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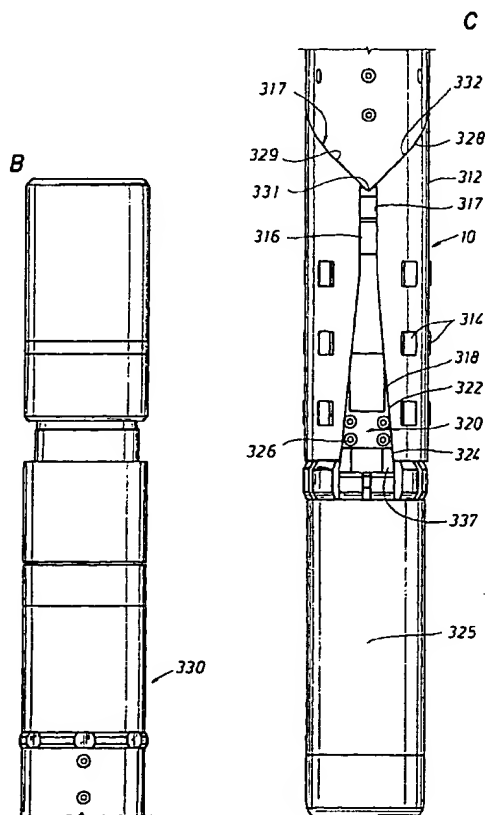
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[Continued on next page]

(54) Title: WELL REFERENCE APPARATUS AND METHOD



(57) Abstract: The reference member (10) provides a permanent reference for the depth and orientation of all well operations and includes a body (11) with an engaging surface (13) for an attaching engagement to the interior surface of an existing casing in a borehole and an orienting surface for orienting well tools within the cased borehole. No sealing engagement is required with the casing (28). The engaging surface (13) on the body has a first non-engaged position where the engaging surface (13) does not engage the casing (28) and an engaged position where the engaging surface (13) does engage the casing (28) which causes adequate engagement between the body (11) and the casing (28) to permanently dispose the well reference member (10) within the casing (28). The well reference member (10) further includes an actuation member (19) for actuating the engaging surface (13) from the non-engaged position to the engaged position. The actuation member (19) may be an expansion member which expands the body (11) having an engaging surface (13) into engagement with the casing (28) or which expands engaging surfaces (13), reciprocally mounted on the body (11), into engagement with the casing (28).

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## WELL REFERENCE APPARATUS AND METHOD

### CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part application of U.S. Patent Application Serial No. 09/573,584, filed May 18, 2000 and entitled "Well Reference Apparatus and Method," which  
5 claims the benefit of 35 U.S.C. 119(e) of U.S. Provisional Application Serial No. 60/134,799, filed May 19, 1999 and entitled "Well Reference Apparatus and Method," both hereby incorporated herein by reference.

### BACKGROUND OF THE INVENTION

The present invention relates generally to apparatus and methods for conducting well  
10 operations at a particular depth and angular orientation within a borehole and more particularly, to apparatus and methods for permanently marking a depth and angular orientation within the borehole, and still more particularly to a reference member set at a particular depth and orientation in the borehole for conducting a well operation such as a sidetracking operation in a single trip into the well.

15 Well operations are conducted at a known location within the well bore. This location may be relative to a formation, to a previously drilled well bore, or to a previously conducted well operation. For example, it is important to know the depth of a previous well operation. However, measurements from the surface are imprecise. Although it is typical to count and measure the sections of pipe in the pipe string as they are run into the borehole to determine the  
20 depth of a well tool mounted on the end of the pipe string, the length of the pipe string may vary due to stretch under its own weight and will also vary with downhole temperatures. This variance is magnified when the pipe string is increased in length, such as several thousand feet. It is not uncommon for the well tool to be off several feet when depth is measured from the surface.

25 In completions it is known to use a no-go ring in the casing string to set a depth location in a well. A typical no-go ring is a thin shouldered device disposed within the casing string which has an inside diameter approximating the drift diameter of the casing string. No-go rings are used to engage and stop the passage of a well tool being run through the well bore. The annular shoulder of a no-go ring is approximately 1/16<sup>th</sup> of an inch thick on each side so that it  
30 will engage the well tool. Other well tools with a smaller diameter are allowed to pass through the no-go ring.

Many well operations require locating a particular depth and azimuth in the borehole for well operations. One such well operation is a sidetracking operation for drilling one or more

lateral boreholes. One typical sidetracking operation for drilling a lateral wellbore from a new or existing wellbore includes running a packer or anchor into the wellbore on wireline or on coiled tubing and then setting the packer or anchor within the wellbore. The packer or anchor is set at a known depth in the well by determining the length of the wireline or coiled tubing run into the wellbore. A second run or trip is made into the wellbore to determine the orientation of the packer or anchor. Once this orientation is known, a latch and whipstock are properly oriented and run into the wellbore during a third trip wherein the latch and whipstock are seated on the packer or anchor. One or more mills are then run into the wellbore on a drill string to mill a window in the casing of the wellbore. The whipstock is then retrieved. Subsequent trips into the wellbore may then be made to drill the lateral borehole to install a deflector or other equipment for down hole operations.

Further, in conventional sidetracking operations, although the depth of the packer or anchor used to support the whipstock is known, the orientation of the packer or anchor within the wellbore is not known. Thus, a subsequent trip must be made into the wellbore to determine the orientation of the packer or anchor using an orientation tool. The packer or anchor has a receptacle with an upwardly facing orienting surface which engages and orients the orientation tool stabbed into the packer or anchor. The orientation tool then determines the orientation of the packer or anchor within the wellbore. Once the orientation of the packer or anchor has been established, the orientation of the latch, whipstock and mill to be subsequently disposed in the wellbore is then adjusted at the surface so as to be properly oriented when run into the wellbore. The latch, whipstock and mill are then run into the wellbore and stabbed and latched into the packer or anchor such that the face of the whipstock is properly directed for milling the window and drilling the lateral borehole.

Since the packer or anchor are not oriented prior to their being set, the receptacle having the orienting surface and a mating connector may have an orientation that could lead to the receptacle being damaged during future operations. If the receptacle is damaged too badly, then it will not be possible thereafter to use it for orientation and latching of an assembly for a subsequent well operation.

It is preferred to avoid numerous trips into the wellbore for the sidetracking operation. A one trip milling system is disclosed in U.S. Patents 5,771,972 and 5,894,889. See also, U.S. Patent 4,397,355.

In a sidetracking operation, the packer or anchor serves as a downhole well tool which anchors the whipstock within the cased borehole against the compression, tension, and torque caused by the milling of the window and the drilling of the lateral borehole. The packer and

anchor have slips and cones which expand outward to bite into the cased borehole wall to anchor the whipstock. A packer also includes packing elements which are compressed during the setting operation to expand outwardly into engagement with the casing thereby sealing the annulus between the packer and the casing. The packer is used for zone isolation so as to isolate the production below the packer from the lateral borehole.

An anchor without a packing element is typically used where the formation in the primary wellbore and the formation in the lateral wellbore have substantially the same pressure and thus the productions can be commingled since there is no zone pressure differentiation because the lower zone has substantially the same formation pressure as that being drilled for the lateral. In the following description, it should be appreciated that a packer includes the anchoring functions of an anchor.

The packer may be a retrievable packer or a permanent big bore packer. A retrievable packer is retrievable and closes off the wellbore while a permanent big bore packer has an inner mandrel forming a flowbore through the packer allowing access to that portion of the wellbore below the packer. The mandrel of the big bore packer also serves as a seal bore for sealing engagement with another well tool, such as a whipstock, bridge plug, production tubing, or liner hanger. The retrievable packer includes its own setting mechanism and is more robust than a permanent big bore packer because its components may be sized to include the entire wellbore since the retrievable anchor and packer does not have a bore through it and need not be a thin walled member. One apparatus and method for determining and setting the proper orientation and depth in a wellbore is described in U.S. Patent 5,871,046. A whipstock anchor is run with the casing string to the desired depth as the well is drilled and the casing string is cemented into the new wellbore. A tool string is run into the wellbore to determine the orientation of the whipstock anchor. A whipstock stinger is oriented and disposed on the whipstock at the surface, and then the assembly is lowered and secured to the whipstock anchor. The whipstock stinger has an orienting lug which engages an orienting groove on the whipstock anchor. The whipstock stinger is thereby oriented on the whipstock anchor to cause the face of the whipstock to be positioned in the desired direction for drilling. The whipstock stinger may be in two parts allowing the upper part to be rotated for orientation in the wellbore. The method and apparatus of U.S. Patent 5,871,046 is limited to new wells and cannot be used in existing wells since the whipstock anchor must be run in with the casing and cannot be inserted into an existing wellbore.

U.S. Patent 5,467,819 describes an apparatus and method which includes securing an anchor in a cased wellbore. The anchor may include a big bore packer. The wall of a big bore

packer is roughly the same as that of a liner hanger. The anchor has a tubular body with a bore therethrough and slips for securing the anchor to the casing. The anchor is set by a releasable setting tool. After the anchor is set, the setting tool is retrieved. A survey tool is oriented and mounted on a latch to run a survey and determine the orientation of the anchor. A coupling  
5 allows the whipstock to be properly oriented on the orientation sleeve at the surface. A mill, whipstock, and a latch or mandrel with orientation sleeve connected to the lower end of the whipstock are assembled and the assembly is then lowered into the wellbore with a lug on the orientation sleeve engaging an inclined surface on the anchor to orient the assembly within the wellbore. The window is milled and then the lateral is drilled. If it is desirable to drill another  
10 lateral borehole, the whipstock may be reoriented at the surface using the coupling and the assembly lowered into the wellbore and re-engaged with the anchor for drilling another lateral borehole.

U.S. Patent 5,592,991 discloses another apparatus and method for installing a whipstock. A permanent big bore packer having an inner seal bore mandrel and a releasable setting tool for  
15 the packer allows the setting tool to be retrieved to avoid potential leak paths through the setting mechanism after tubing is later sealingly mounted in the packer. An assembly of the packer, releasable setting tool, whipstock, and one or more mills is lowered into the existing wellbore. The packer may be located above or below the removable setting tool. A survey tool may be run with the assembly for proper orientation of the whipstock. A lug and orienting surface are  
20 provided with the packer for orienting a subsequent well tool. The packer is then set and the window in the casing is milled. The whipstock and setting tool are then retrieved together leaving the big bore packer with the seal bore for sealingly receiving a tubing string so that production can be obtained below the packer. One disadvantage of the big bore packer is that its bore size will not allow the subsequent smaller sized casing to be run through its bore.

25 U.S. Patent 5,592,991 describes the use of a big bore packer as a reference device. However, once the releasable setting tool and whipstock are removed from the big bore packer, the packer no longer has sealing integrity. The big bore packer only seals the wellbore after another assembly is lowered into the well and a stinger is received by the big bore packer to create or establish sealing integrity. The big bore packer does double duty, first it serves as the  
30 anchor for the milling operation and then it becomes a permanent packer to perform the completion.

In both the '891 and '991 patents, the whipstock assembly must latch into the packer or anchor to anchor the whipstock and withstand the compression, tension, and torque applied during the milling of the window and the drilling of the lateral borehole. Further, the use of a

big bore packer requires a packer assembly which can withstand a 5,000 psi pressure differential and thus all of its components must have a minimum 5,000 psi burst and collapse capability.

The big bore packer has the additional disadvantage of having a mandrel extending  
5 through it and on which is mounted the cones for activating the slips of the packer. The mandrel is subsequently used as a seal bore which is then used for sealing with a tubing string. This mandrel is not only an additional mechanical part but requires a reduction in the diameter of the bore of the packer.

The present invention overcomes the deficiencies of the prior art.

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## SUMMARY OF THE INVENTION

The well reference apparatus and method of the present invention includes a reference member permanently installed within the borehole at a preferred depth and orientation in the well. The reference member provides a permanent reference for the depth and orientation of all well operations, particularly in a multi-lateral well. The well reference member includes a body  
15 with an engaging surface for an attaching engagement to the interior surface of an existing casing in a borehole and an orienting surface for orienting well tools within the cased borehole. No sealing engagement is required with the casing. The engaging surface on the body has a first non-engaged position where the engaging surface does not engage the casing and an engaged position where the engaging surface does engage the casing. The engaging surface  
20 may be any surface which causes adequate engagement between the body and the casing to dispose the well reference member within the casing. The well reference member further includes an actuation member for actuating the engaging surface from the non-engaged position to the engaged position. The actuation member may be an expansion member which expands the body having an engaging surface into engagement with the casing or which expands  
25 engaging surfaces, reciprocally mounted on the body, into engagement with the casing. In a preferred embodiment, the diameter of the through bore of the well reference member in the engaged position is at least 70% of the diameter of the casing.

A setting member extends through the well reference member and includes a first surface engaging one end of the well reference member and a second surface engaging the  
30 other end of the well reference member such that the well reference member is captured and held in between the first and second surfaces and thus mounting the well reference member onto the setting member. The setting member is actuated to engage with the casing either by

expanding the body of the well reference member into the engaging position or expanding the engaging surfaces reciprocally mounted on the body into the engaging position.

A release member may be used to release the engagement of the well reference member from the casing. The release member is attached to one end of the well reference member body thus mounting the well reference member onto the release member. A portion of the release member extends through the well reference member body and that portion has a lower end which extends below the lower end of the well reference member. The release member portion also includes a piston member engaging the top of the actuation member on the well reference member for driving the actuation member out of the engagement with the well reference member body to release the well reference member from engagement with the casing. The release member is removed with the release member engaging the lower end of the well reference member to also remove the well reference member.

The assembly of the present invention includes disposing a landing sub, setting member, and reference member on the end of a pipe string. An orienting tool such as an MWD collar is disposed in the pipe string above the landing sub. This assembly is lowered into the borehole on the pipe string. Once the preferred depth is attained, the MWD collar is activated to determine the orientation of the reference member. If the reference member is not oriented in the preferred direction, the pipe string is rotated to align the reference member in the preferred direction. This process is repeated for further corrective action and to verify the proper orientation of the reference member. Upon achieving the proper orientation of the reference member, the reference member is set within the borehole and the pipe string is disconnected from the reference member and the setting member is retrieved. The pipe string may also include a well tool for performing a drilling operation in the borehole.

The present invention features apparatus and methods that permit multiple sidetracking-related operations to be performed using fewer runs into the wellbore. The reference member is placed in the wellbore during the initial trip into the wellbore, and remains there during subsequent operations. Further, the reference member provides a receptacle for reentry runs into the well.

In another aspect, the invention provides for all of the apparatus used during subsequent sidetracking operations to be commonly oriented using only a single orientation on the reference member.

The well reference apparatus and method may be used in a sidetracking operation and include the reference member disposed on setting member, a packer or anchor, a whipstock, a mill assembly, and an orientation device, such as an MWD collar and bypass valve, disposed



above the mill assembly in a pipe string extending to the surface. The entire assembly is lowered into the borehole in one trip into the well. Once the reference member has reached the desired depth, fluid flows through the MWD collar allowing the MWD collar to determine and communicate the orientation of the reference member within the borehole. As previously  
5 described, the pipe string may be rotated to adjust the orientation of the reference member until the desired orientation is achieved.

Once the orientation is complete, the bypass valve is closed and the setting tool is actuated hydraulically to set the reference member permanently within the casing of the borehole. An anchor or packer is also set. A packer is preferred because it sealingly engages  
10 the wall of the casing and therefore allows for isolation between production zones. Once the anchor is set, the mill assembly is released from the whipstock and a window is milled through the casing and into the formation.

In another embodiment of the method, an assembly is provided for drilling another lateral borehole spaced out from an earlier lateral borehole. This assembly includes a locator  
15 sub, a string of spacer subs extending from the locator sub to a retrievable packer which supports a whipstock and mill assembly. No orientation member is required since the assembly is oriented on the reference member. The retrievable packer supports the upper end of the assembly within the borehole to prevent the instability of the milling and drilling operations on the whipstock.

20 It should also be appreciated that the reference member has a through bore permitting the performance of operations in that portion of the borehole below the reference member.

Thus, the present invention comprises a combination of features and advantages which enable it to overcome various problems of prior devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading  
25 the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed description of the preferred embodiments of the present invention, reference will now be made to the accompanying drawings, wherein:

30 Figure 1 is a side elevation view partly in cross section of a preferred embodiment of the well reference member of the present invention in the non-engaged position with a casing;

Figure 2 is a cross sectional view taken at plane 2-2 of Figure 1;

Figure 3 is a side elevation view partly in cross section of well reference member of Figure 1 in the engaged position with the casing;

Figure 4 is a cross sectional view taken at plane 4-4 of Figure 3;

Figure 5 is a side elevation view of another preferred embodiment of the well reference  
5 member of the present invention;

Figure 6 is a cross sectional view taken at plane 6-6 of Figure 5;

Figure 7 is an elevation view of the well reference member of Figure 5 with a setting  
tool;

Figure 7A is an elevation view of an alternative embodiment of the wedge shown in  
10 Figure 5;

Figure 8 is a cross-sectional view of the well reference member of Figure 7;

Figure 9 is a magnified cross-section of the lower end of the well reference member and  
setting tool of Figure 7 in the running position;

Figure 10 is a magnified cross-section of the lower end of the well reference member  
15 and setting tool of Figure 7 in the setting position;

Figure 11 is a cross-sectional elevation view of a preferred embodiment of the reference  
member of the present invention installed within a casing string in a well bore;

Figures 12A and 12B are cross-sectional elevational views of the reference member of  
Figure 11 and a setting tool disposed within the reference member to actuate the reference  
20 member into engagement with the casing;

Figure 13 is a cross-sectional view taken at plane A-A in Figure 12B;

Figure 14 is a cross-sectional view taken at plane B-B in Figure 12B;

Figure 15 is a cross-sectional view taken at plane C-C in Figure 12B;

Figure 16 is a cross-sectional view of the assembly of Figures 12A-B with the slips of  
25 the reference member in the set or engaging position;

Figure 17 is a cross-sectional elevation view of the assembly of Figures 12A-B with the  
actuation pistons having been actuated to shear the connection between the setting tool and  
reference member;

Figure 18 is a cross-sectional elevation view of the assembly of Figures 12A-12B with  
30 the release dogs of the setting tool in their release position;

Figure 19 is a cross-sectional elevation view of the setting tool being retrieved from the  
reference member;

Figures 20A-C are a cross-sectional elevation view of a well assembly including a reference member and setting tool mounted on a landing sub attached to a spline sub which in turn is connected to a retrievable packer and whipstock for running into the wellbore;

Figures 21A-C are a cross-sectional view of the assembly of Figures 20A-B with the retrievable packer in the set position;

Figures 22A-C are a cross-sectional view of the assembly of Figures 20A-B while milling a window in the casing string;

Figures 23A-C are elevation views, partly in cross-section, illustrating the setting tool, retrievable packer and whipstock being retrieved from the wellbore, leaving the reference member;

Figures 24A-C are an elevation view of a subsequent assembly including a deflector and retrievable packer being landed and oriented on the reference member for re-entering the lateral borehole;

Figures 25A1-3, B1-3, C1-3, and D1-3 are cross-sections of the present invention lowered and oriented on the reference member for cutting another window and drilling another lateral borehole in the formation using the reference member of the present invention; and

Figures 26A1-3, B1-3 and C1-3 are cross-sections of the present invention lowered and oriented on the reference member for installing a tie-back insert in a lateral borehole using the reference member of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring initially to Figures 1-4, there is shown a preferred reference member 10 of the present invention disposed within a casing string 28 in a borehole 30. Reference member 10 is a depth locator and an angular orientor having a known depth and angular orientation within cased borehole 30. The reference member 10 is neither a packer nor an anchor because it neither seals with the casing 28 nor serves as an anchor to withstand the compression, tension, and torque caused during a well operation. A packer or anchor is typically used in conjunction with the reference member 10. The reference member 10 is completely divorced from the packer or anchor and is used only for depth location and orientation. As will be more fully hereinafter described, once reference member 10 is set within casing 28, it serves both as a reference for depth and a reference for angular orientation within the well bore 30.

In using the terms "above", "up", "upward", or "upper" with respect to a member in the well bore, such member is considered to be at a shorter distance from the surface through the bore hole 30 than another member which is described as being "below", "down", "downward",

or "lower". "Orientation" as used herein means an angular position or radial direction with respect to the axis of the borehole 30. In a vertical borehole, the orientation is the azimuth. The depth is defined as that distance between the surface of the cased borehole 30 and the location of the reference member 10 within the cased borehole 30. "Drift diameter" is a diameter, which is smaller than the diameter  $D_c$  of the casing 28 taking into account the tolerance of the manufactured casing, through which a typical well tool will safely pass. Typically the drift diameter is approximately 1/8 inch smaller than the normal diameter of the casing 28.

The term "packer" and "anchor" as used herein are defined as a downhole well tool which anchors another well tool within the cased borehole to withstand the compression, tension, and torque caused during a well operation. The packer and anchor have slips and cones which expand outward to bite into the cased borehole wall to anchor another well tool. A packer differs from an anchor in that a packer includes packing elements which expand outwardly into sealing engagement with the casing to seal the annulus between the mandrel of the packer and the casing. Where the well tool is a whipstock or deflector, the packer and anchor anchors the whipstock against the compression, tension, and torque caused by the milling of the window in the casing and the drilling of the lateral borehole.

It is intended that the reference member 10 be permanently installed within the borehole 30. Permanent is defined as the reference member 10 being maintained in the cased borehole 30 at least throughout drilling operations. It should be appreciated, however, that the reference member 10 may be retrievable as hereinafter described.

As shown in Figures 1-4, well reference member 10 includes a body 11 with an engaging surface 13 for an attaching engagement to the interior surface 15 of casing 28 in borehole 30 and one or more orienting surfaces 17 for orienting well tools within the cased borehole. No sealing engagement is required with the casing 28. The engaging surface 13 on body 11 has a first non-engaged position shown in Figures 1 and 2 where the engaging surface 13 does not engage the casing 28 and an engaged position shown in Figures 3 and 4 where the engaging surface 13 does engage the casing 28. In the non-engaging position, the engaging surfaces have an outer dimension  $D_w$  thereby providing a radial clearance  $D_c - D_w$ . The engaging surface may be any surface which causes adequate engagement between the engaging surfaces 13 on body 11 and surface 15 on casing 28 to permanently dispose the well reference member 10 within casing 28. In the engaging position, engaging surface 13 bitingly and/or frictionally engages surface 15 of casing 28 to maintain well reference member 10 within casing 28. The well reference member further includes an actuation member 19 for actuating the engaging surface 13 from the non-engaged position to the engaged position. The actuation

member 19 may be an expansion or wedge member which expands body 11 with engaging surface 13 into engagement with inner surface 15 of casing 28 or which expands engaging surfaces, reciprocally mounted on body 11, into engagement with casing 28. In the engaged position,  $D_w$  approximates  $D_c$ . Preferably, the inner dimension  $D_i$  of body 11 in the engaged position is greater than the outer dimension  $D_w$  in the nonengaged position such that a well reference member in the nonengaged position will pass through a well reference member in the engaged position.

Referring now to Figures 5-7, there is shown a preferred embodiment of the well reference member 10. Well reference member 10a of Figures 5-7 includes a body 312 in the form of a sleeve having an engaging surface in the form of a plurality of slips 314 integrally disposed around the external surface of body 312. Body 312 also includes a slot 316 having an upper end with parallel sides 317 and a lower end having tapered sides or edges 324 forming a V or truncated cone shaped slot 318. V-shaped slot 318 receives an actuating member in the form of a wedge 320 having tapered outer edges 322 which are complimentary to the tapered edges 324 of body 312. As wedge 320 moves into slot 318, body 312 expands concentrically radially creating a type of press fit into the casing 28. The preferred embodiment has simplicity in that it is thin walled member comprised of only two pieces, i.e., a two-piece well reference member.

It should be appreciated that slips 314 have teeth which bitingly engage the inside surface 15 of casing 28. This engagement may be varied by varying the number of teeth on slips 314 or by varying the number of slips 314. The slips 314 place less stress placed into casing 28 than typical liner hangers. Because individual slips are not being used in the preferred embodiment, as in a typical liner hanger, there is a uniform stress distribution around the body 312 which is lower than that of the prior art. Although there may be hot spots at individual groupings of teeth, slips 314 can be evenly spaced around the surface of body 312 while achieving the same load carrying capacity. Thus, the present invention has a more uniform load distribution of engagement between body 312 and casing 28. This causes less damage to the casing. Although teeth have been shown on slips 314, it should be appreciated that any frictional surface around body 312 may be used such as buttons instead of individual slip pads with teeth.

As shown in Figure 6, the edges 322, 324 of wedge 320 and body 312, respectively, are radial cuts along the radius  $R$  of body 312 and along a helical surface so that the inside chordal length 333 of the cut is less than the outside chordal length 335. This causes the inside edges 322a of wedge 320 to be smaller than the outside edges 322b. As wedge 320 moves upwardly

into slot 318, edges 322, 324 interengage, because of chordal lengths 333, 335, thereby preventing wedge 320 from moving interiorally of the opening formed by inside chord 333 of body 312. The outside surface of wedge 320 is maintained by casing 28. The well reference member 10a is fixed into the cased borehole 30 as wedge 320 moves upwardly into the V-shaped slot 318 and expands the diameter  $D_w$  of the body 312 causing the slips surfaces 314 to contact the inside surface 15 of casing 28. The wedge 320 is driven into position by a setting tool preferably designed to be removed from the well after setting in order to open the wellbore for use by other tools.

It should be appreciated that the wedge 320 may be of any size and edges 322, 324 may have any taper preferably less than  $45^\circ$  from axis 325. The smaller the angle of the taper, the longer the stroke that is required by wedge 320 to achieve a predetermined expansion of body 312. A smaller taper angle better maintains wedge 320 within mule shoe slot 318 since a smaller taper provides more hoop stress for the mechanical force provided by wedge 320. If the angle is made larger, less hoop stress is achieved. The preferred range of angles of edges 322, 324 for wedge 320 is  $5-15^\circ$  and most preferably  $10^\circ$  from the axis 325. This provides a stroke of six inches by wedge 320 to achieve adequate expansion of well reference member 10a for a 9-5/8 inch casing. This adds between 3/8 and 1/2 inch to the diameter  $D_w$  of well reference member 10a.

Figure 7A shows another embodiment of the body and wedge where each wedge member 300 is one half of the body. The wedges members are two halves of a circle or  $180^\circ$  in arcuate shape. Each half 302 has a helical wedge cut 304 that mates with the other half so that when the halves are slid along their central axis 306 the outside diameter of the combination increases. It should also be appreciated multiple wedges may be disposed on the body of well reference member 10. For example, there may be multiple wedges disposed around body 312, such as four wedges each approximately  $90^\circ$  from each other or three wedges each approximately  $120^\circ$  from each other.

The upper end of body 312 includes an upwardly facing orienting surface 328 forming orientation member 317. The orienting surface 328 of orientation member 317 includes an inclined surface 329 extending from an upper apex to a lower opening 331 of V-shaped slot 318. Orientation member 317 is sometimes referred to as a muleshoe. The orientation surface 328 is adapted to engage a complimentary muleshoe on a well tool. The complimentary mule shoe surfaces are radial helixes.

The lower terminal end 336 of well reference member 10a is chamfered at 387 so that the lowermost annular pointed end is adjacent casing 28. The lower terminal end 336 will be

against the casing 28 after the well reference member 10a has been expanded and set within casing 28. It is desirable for the lower terminal end 336 to be as close to the casing wall 15 as possible to avoid causing any well tools to hang up in the well reference member 10a as they pass therethrough, particularly as a well tool passes upwardly through the bore 323 of body 312.

The reference member 10a has a diameter 325 forming a central bore 323 therethrough with diameter 325 preferably approximating the drift diameter. Diameter 325 of reference member 10a preferably has a minimum diameter of at least 4 inches. It can be appreciated that the inside diameter 325 in its contracted position may be adjustable by sizing the V-shaped slot 318.

After being expanded to the engaged position, the inside diameter  $D_i$  of the well reference member 10a is also large enough to allow the passage of another well reference member 10a in the collapsed and nonengaged position. By allowing the same sized well reference member in its contracted position to pass through the expanded bore of another well reference member, multiple well reference members can be disposed anywhere in the well and may be stacked within the well.

The wall thickness  $T$  of body 312 is only as thick as is required to withstand the forces that will be applied to well reference member 10a. Thus, the body 312 has a minimum wall thickness providing a maximum central bore 323 through body 312. Because there are no overlapping components, wall 313 of body 312 can be as thick as needed to engage and orient a subsequent well tool. In one preferred embodiment, the wall thickness  $T$  of body 312 is  $3/8$  of an inch thick. Thus, the inside diameter  $D_i$  of body 312 is less than one inch, preferably  $3/4$  of an inch, smaller than the diameter  $D_c$  of the casing 28. In a preferred embodiment, the diameter  $D_i$  of the through bore of the body 312 in the engaged position is less than 30% smaller than the diameter  $D_w$  of the casing 28 and at least 70% of the diameter  $D_w$  of the casing 28.

The inside diameter 325 of reference member 10a in the engaged position is maximized with respect to the inside diameter  $D_c$  of casing 28. For example, it is typical to have a 7 inch casing as the innermost casing string in the well bore. A 7 inch casing has an inside diameter of approximately 6 inches and in a 7 inch casing, the diameter 325 of reference member 10a has a inside diameter of at least 5 inches which is only one inch smaller than the diameter of casing 28. More preferably diameter 325 has a diameter of  $5-1/2$  inches which is only  $1/2$  inch smaller than the diameter  $D_c$  of casing 28. It is preferred that the diameter 325 be no less than  $3/4$  inch smaller than the diameter  $D_c$  of casing 28. This will allow a  $4-1/2$  liner with 5 inch couplings to pass through reference member 10a.

Diameter 325 of reference member 10a in the engaged position is sufficiently large to allow the next standard sized liner or casing string to pass therethrough. For example, if casing 28 were a 7 inch casing, the next standard size pipe would be 4-1/2 inch pipe, such as a liner. In comparison, a 7 inch big bore packer has a throughbore of less than 4 inches and will not  
5 allow the passage of 5 inch couplings or a 4-1/2 inch liner. If a big bore packer were used, a reduced size liner would be required such as a 3-1/2 inch liner so as to pass through the bore of the big bore packer. If casing 28 were 9-5/8 inch casing, reference member 10a would have a nominal diameter 325 in the engaged position of 8-1/2 inches and would then accommodate a 7-5/8 inch pipe. The diameter 325 through reference member 10a would then preferably be  
10 between 7-3/4 and 8 inches. With the well reference member 10a in the expanded position, its outside diameter Dw is approximately 8-3/8 inches.

Referring now to Figure 11 and Figures 12A-B, there is shown another embodiment of reference member 10b. Well reference member 10b includes upper and lower slips 12, 14, an orientation member 16, upper and lower cones 18, 20, and a ratchet ring 22. Reference member  
15 10b is preferably made of steel. In one embodiment, upper and lower slips 12, 14 include teeth 24, 26, respectively, which bitingly engage the interior wall of casing 28. The slips 12, 14 are split annular members which are collapsed in their contracted position shown in Figures 12A and B and then are expanded to their expanded position upon the reference member 10 being set within casing 28 as shown in Figure 1. The upper and lower slips 12, 14 have a diameter  
20 which is actually greater than the inner diameter of casing 28. As shown in Figure 11, upon slips 12, 14 being expanded into biting engagement with the inside diameter of casing 28, there is substantially complete wall contact between slips 12, 14 and casing 28.

Upper and lower slips 12, 14 and upper and lower cones 18, 20 have cooperating wedge surfaces 60, 62 causing upper and lower slips 12, 14 to expand into biting engagement with  
25 casing 28 as upper and lower slips 18, 20 move away from each other, *i.e.* lower cone 20 moving downwardly and upper cone 18 moving upwardly against upper and lower slips 12, 14. Although upper and lower slips 12, 14 are shown as split annular members, it should be appreciated that upper and lower slips 12, 14 may include slip segments mounted within windows cut in a mandrel member thereby allowing the slip segments to expand and contract  
30 within the mandrel windows. Optionally, shear bolts may be provided to hold upper and lower slips 12, 14 in position until actuated into their expanded position. The actuation shears the shear bolts allowing upper and lower slips 12, 14 to expand outwardly.

The upper cone member 18 includes a full annular body 32 having an inner reduced diameter portion 34 in which is received a full annular member 36 of lower slips 20. Lower



annular member 36 has an outer reduced diameter 38 with wickers 40 cut in the outer surface of member 36. Ratchet ring 22 is a split ring which includes inner ratchet teeth 41 for engaging wickers 40. Upper body 32 includes a further inner reduced diameter portion 42 in which is mounted ratchet ring 22 and retained thereon by a threaded retainer ring 44. As lower annular member 36 is received within the reduced diameter portion 34 of upper cone member 32, the ratchet teeth 41 of ratchet ring 22 engage wickers 40. Ratchet teeth 41 and wickers 40 only allow upper and lower cones 18, 20 to move away or separate from each other and do not permit them to move towards or collapse towards each other thereby maintaining upper and lower slips 12, 14 in the engaged position as hereinafter more fully described. The wickers 40 are lengths of thread-like members which are tapered in only one direction. Thus, the engagement between ratchet ring 22 and wickers 40 of annular member 36 only allows annular member 36 to move in one direction with respect to upper cone member 32. As cones 18, 20 move apart, ratchet ring 22 and wickers 40 prevent upper and lower cones 18, 20 from moving to a contracted position.

Referring now to Figures 11, 12A-B, and 13, upper and lower cones 18, 20 further include an aperture 52, 54 for housing a shear member 56, 58. Upper cone 18 is integral with upper cone member 32. Lower cone 20, however, includes an inner reduced diameter annular portion 46 which is received within a counter bore 48 on the end of lower cone member 36. A plurality of Belville springs 50 are disposed between the bottom of counterbore 48 and the upper terminal end of reduced diameter portion 46 of lower cone 20. Belville springs 50 place a downward force against lower cone 20 and against lower slip 14. Belville springs 50 serve as an energy storing member whereby as lower slip 14 engages casing 28, Belville springs 50 tend to expand to take up any slack in the assembly of reference member 10b. It should be appreciated that Belville springs 50 may not be required in certain assemblies.

The teeth 24, 26 of slips 12, 14, respectively, are only required to bite into casing 28 so as to maintain reference member 10b in position while locating and orienting the well tool. The biting engagement of slips 12, 14 prevent the reference member 10b from rotating about the axis 74 of casing string 28. Once the angular orientation member 16 is set, its rotation within casing 28 must be prevented to avoid changing the orientation reference. It is unnecessary for slips 12, 14 to have a biting engagement which is comparable to that of an anchor which must absorb the impact of the well operation. Although upper and lower slips 12, 14 do not include vertical serrations to assist in preventing rotation between reference member 10b and casing 28, it should be appreciated that vertical serrations or carbide buttons may be included on upper and lower slips 12, 14 to enhance the engagement between reference member 10b and casing

28. See for example U.S. Patent Application Serial No. 09/302,738 filed April 30, 1999, entitled Anchor System for Supporting a Whipstock.

The upper slip 12 includes an upwardly extending annular body 64 forming orientation member 16. Orientation member 16 includes an inclined surface 66 extending from an upper apex 68 to a lower slot 70. Although orientation member 16 is shown as having an orientation surface 66 and slot 70 for receiving an orientation key on a well tool, it should be appreciated that the inclined surface 66 and slot 70 may be included on the well tool with the orientation key being the orientation member disposed on upper slip 12. It should also be appreciated that the reference member 10b may include the key 72 and not orienting surface 66 so as to avoid the collection of debris which falls into the borehole and which might ultimately block the orienting surface 66 and orientation slot 70.

The reference member 10b has a central bore 80 therethrough with a diameter which is preferably only slightly greater than the drift diameter. A slightly smaller inside diameter is required of the reference member because of the orientation member 16 which must engage an orientation key 72 of the well tool assembly. Bore 80 of reference member 10b preferably has a minimum diameter of at least 4 inches. If the reference member 10b were used strictly as a depth locator, then orienting surface 66 and slot 70 could be eliminated allowing the inside diameter of bore 80 of reference member 10b to approximate the drift diameter.

The inside radius 76 of the bore 80 of reference member 10b in the set position shown in Figure 11 is maximized with respect to the inside radius 78 of casing string 28. For example, it is typical to have a 7 inch casing as the innermost casing string in the well bore. A 7 inch casing has an inside diameter of approximately 6 inches and in a 7 inch casing, the bore 80 of the reference member 10b has a inside diameter of at least 5 inches which is only one inch smaller than the diameter of casing 28. More preferably bore 80 has a diameter of 5-1/2 inches which is only 1/2 inch smaller than the diameter of casing 28. It is preferred that the diameter of bore 80 be no less than 3/4 inch smaller than the diameter of casing 28. This will allow a 4-1/2 liner with 5 inch couplings to pass through reference member 10b.

Bore 80 of reference member 10b is sufficiently large to allow the next standard sized liner or casing string to pass therethrough. For example, if casing 28 were a 7 inch casing, the next standard size pipe would be 4-1/2 inch pipe such as a liner. In comparison, a 7 inch big bore packer has a throughbore of less than 4 inches and will not allow the passage of 5 inch couplings or a 4-1/2 inch liner. If a big bore packer were used, a reduced size liner would be required such as a 3-1/2 inch liner so as to pass through the bore of the big bore packer. If casing 28 were 9-5/8 inch casing, reference member 10b would have a nominal diameter of 8-

1/2 inches and would then accommodate a 7-5/8 inch pipe. The diameter of bore 80 through reference member 10b would then preferably be between 7-3/4 and 8 inches.

Well reference member 10 need only have a sufficient engagement with the casing 28 so as to accommodate the minimal compression and torque required during the depth location and orientation of another well tool. The reference member 10 is not required to withstand the compression, tension, and torque caused by the well operation, such as the milling of a window. An independent packer or anchor are provided above the reference member 10 to withstand the rigors of the well operation. In particular, the reference member 10 need not withstand any force required to shear off any shear connection in a well tool installed in the well bore 30. Further, the reference member 10 is not required to handle the torque transmission due to any down hole operation. The torque transmission is handled by a completely separate tool and independent with the reference member 10 being used purely for orientation and depth location.

The construction of reference member 10 need only have sufficient mechanical integrity to handle the location and orientation of the subsequent well tool or well assembly. It need not handle the rigors of the well operation since this will be handled by an independent packer or anchor which is disposed adjacent the reference member 10.

Further since the reference member 10 is not be required to withstand the compression, tension, and torque of the well operation, the reference member 10 is not latched to the well tool or well assembly during the well operation and thus the reference member 10 does not require a latch. The reference member 10 might be termed an insertable locator tool. So long as the reference member is not used as an anchor for the well operation, no latch is required. The reference member 10 merely engages the well tool assembly. Still further reference member 10 does not seal with the casing 28 and thus does not require any packing elements so as to serve as a packer.

It should be appreciated that the setting tool for the packer or anchor could also form a part of the setting tool for the reference member 10 and both be actuated simultaneously. This combination setting tool would then be retrieved with the packer or anchor. The combination setting tool would actuate two sets of slips, one set for the reference member and one set for the packer or anchor.

Referring now to Figure 7, there is shown wedge 320 on well reference member 10a mounted on a setting tool 330 by a plurality of shear screws 326. As shown, there are four shear screws 326 although there may be any number of shear screws 326. The lower end of setting tool 330 includes a downwardly facing orienting surface 332 for matingly engaging with upwardly orienting surface 328 on well reference member 10a.

Referring now to Figures 8-10, the setting tool 330 is connected to a splined assembly 289 which in turn is connected to a rotary connection 352 attached to the end of a work string (not shown). The setting tool 330 includes an upper tubular member 301 threaded at its upper end to splined assembly 289. A sleeve 299 having a downwardly facing orienting surface 332 is disposed around a portion of tubular member 301 and a crossover sub 298 is mounted within the lower end of upper tubular member 301. A mandrel 340 is threaded at its upper end to crossover sub 298 and extends through well reference member 10a and is attached at its lower end to a cap 356. An outer tubular member 366 is attached at its lower end to cap 356 and extends upwardly around cap 356. A hydraulic passageway 354 extends through crossover sub 298 and mandrel 340 and is closed by cap 356 at its lower end. Hydraulic passageway 354 communicates with the surface through splined assembly 289 and the flowbore of the work string.

Mandrel 340 and outer tubular member 366 form a cylinder 362 housing a piston 360. Piston 360 includes seals 364 which sealingly engage the inner surface of outer tubular member 366 and the outer surface of mandrel 340 and is held in place on mandrel 340 by shear screws 344 or similar releasable attachment means. A collet 342 is releasably attached to mandrel 340 by shear screws 346 or a similar releasable attachment means. Collet 342 includes an upper collar 341 having a plurality of downwardly extending collet fingers 334 with enlarged heads 382 on the end thereof. Collet heads 382 form an upwardly facing shoulder 383 which engages the lower end 336 of well reference member 10a. As best shown in Figure 7, the wedge member 320 of well reference member 10a is attached to two of the collet fingers 383 by shear screws 326 or similar releasable attachment means.

Collet heads 382 project radially outward of the outer surface of well reference member 10a to protect the lower end 336 of well reference member 10a as it is lowered through the casing 28. The outside diameter of heads 382 are slightly greater than the outside diameter of body 312 and are chamfered at 385. Heads 382 prevent lower terminal end 336 from hitting anything in the borehole as it passes therethrough. In particular, it is important that nothing engage the lower terminal end 337 of wedge 320 which would tend to drive wedge 320 prematurely up into slot 318.

In the unactuated position shown in Figures 8 and 9, the downwardly facing orienting surface 332 and the upwardly facing shoulders 383 of collet heads 382 hold well reference member 10a in the non-expanded and non-engaged position. Collet fingers 334 are supported in their radially outermost position by the upper end of piston 360 thus preventing collet fingers

334 from being forced radially inward by any force applied to the outer surfaces 376 of collet heads 382.

Referring now to Figure 9, upon pressuring up through the hydraulic passageway 354 from the surface, fluid passes through passageway 354 and through ports 358 communicating  
5 with cylinder 362. Pressure is applied to the end of piston 360 causing the piston 360 to be displaced upwardly. Shear screws 344 are sheared by this upward movement. The piston continues its upward movement until it engages downwardly facing shoulder 370 on the collar 341 of collet 342. As can be seen in Figure 10, in this position a reduced diameter portion 371  
10 around the mid-portion of piston 360 is aligned with collet heads 382. This alignment allows the collet heads 382 to move radially inward into the annular area formed by reduced diameter portion 371 such that piston 360 no longer supports collet fingers 334. Surface 276 on fingers 334 assists by camming fingers 334 inwardly so as to disengage with the lower end 336 of well  
reference member 10a. As the collet fingers 334 collapse and piston 360 engages shoulder 370 of collet 334, shear screws 346 are then sheared releasing collet 334 from mandrel 340  
15 allowing further upward movement of piston 360, collet 342, and wedge 320. The well reference member 10a remains stationary because of the engagement of orienting surfaces 328, 332.

The upward movement of wedge 320 is constrained by edges 322, 324 of wedge 320 and V-shaped slot 318 and the interior surface of casing. As piston 360 continues to move  
20 upwardly, wedge 320 is forced up into slot 318 forcing the well reference member 10a to expand into its engaged position. Ultimately the force required to move wedge 320 further into slot 318 reaches the predetermined shear value of shear screws 326. Once the shear value is reached, the shear screws 326 shear, therefore releasing wedge 320 from setting tool 330. The hydraulic actuation of setting tool 330 has moved wedge 320 upwardly and into V-shaped slot  
25 318 expanding the outside diameter of body 312 causing slips 314 to bitingly engage the interior surface of casing 28. Now all of the collet fingers 334 move up underneath inside of body 312 and setting tool 330 is completely released from reference member 10. Setting tool 330 is then retrieved through the inside diameter of body 312.

It should be appreciated that only one or the other of the slot 318 and wedge 320 need  
30 have tapered edges. For example, the slot 318 may only have parallel edges 317 and no tapered edges with the wedge 320 having tapered edges 322 to spread the parallel edges 317 apart to expand body 312 as wedge 320 is forced between parallel edges 317. Likewise, the wedge may have only parallel edges and slot 318 have tapered edges 324 whereby as the wedge is driven

between tapered edges 324, body 312 expands. Alternatively, it should be appreciated that the body 312 may be moved relative to a stationary wedge 320 to expand body 312.

It should be appreciated that the wedge 320 may be actuated other than by hydraulic means. For example, wedge 320 may be actuated mechanically or pyrotechnically.

5 Referring still to Figures 8-9, the splined assembly 289 allows setting tool 330 to be rotationally adjusted as the surface so that the orienting surfaces 328, 332 are properly oriented. The splined assembly 289 comprises an upper spline sub 294, a spline nut 292, a lower spline sub 290, and a retaining ring 288. The lower spline sub 290 threadably engages upper tubular member 301 of well reference member 10a at its lower end and has splines on its upper end.  
10 The splines mesh with mating splines on the upper spline sub 294 that sealingly engages the tubular member 298. The spline nut 292 threadably engages the lower spline sub 290 and maintains the position of the upper spline sub 294 at a shoulder.

Referring now to Figures 12A-B, there is shown a setting member 90 for setting reference member 10b within casing 28. Reference member 10b is disposed on setting member  
15 90 which in turn is supported on the lower end of an orienting member such as a landing sub 86 connected to a well tool 84 for performing a well operation. The landing sub 86 includes an extension member or stinger 85 which is received within bore 80 of reference member 10b with stinger 85 including reference key 72 to properly orient the well tool.

Setting member 90 includes an inner mandrel 91 having a full diameter portion 92 with  
20 upper and lower reduced diameter portions 94, 96. Upper and lower threaded sleeves 98, 100, respectively, are threadingly mounted at 102, 104, respectively, on full diameter portion 92. Upper outer sleeve 98 and upper inner mandrel 94 form an upper cylinder 106 in which is disposed an upper piston 108. Likewise, lower outer sleeve 100 and lower inner mandrel 96 form a lower cylinder 110 housing a lower piston 112. It should be appreciated that seals are  
25 provided on pistons 108, 112 such as 130, 132. Upper cylinder 106 is closed at its upper end by the threaded connection at 113 of stinger 85 of landing sub 86 and upper inner mandrel 94. A dog collar 114 with a bore 116 receives lower inner mandrel 96 and is sized to be received within lower outer sleeve 100 to close the lower end of lower cylinder 110. Inner mandrel 91 includes a central hydraulic passageway 118 extending the length thereof communicating with  
30 a similar hydraulic passageway 120 through the stinger 85 of landing sub 86 which in turn communicates with hydraulic passageway 122 extending through the well tool. Inner mandrel 91 also includes upper and lower ports 124, 126 communicating with that portion of upper and lower cylinders 106, 110 between pistons 108, 112 and full diameter portion 92 of mandrel 91.

On the outboard ends of pistons 108, 112, there are disposed shear members 56, 58, respectively. It can be seen that shear members 56, 58 are mounted on pistons 108, 112 by annular retainer members disposed on the outboard ends of the pistons 108, 112. Shear members 56, 58 extend radially outwardly through slots 136, 138 in upper outer sleeve 98 and lower outer sleeve 100. Thus, as pistons 108, 112 are actuated, their actuation causes upper and lower cones 18, 20 to move with pistons 108, 112.

Referring now to Figures 12B, 14 and 15, dog collar 114 includes a shear connection 140, such as a ring with a shear screw, extending through the wall of collar 114 and into an annular groove 142 around lower inner mandrel 96. Figure 15 shows the shear connection between dog collar 114 and lower inner mandrel 96. Dog collar 114 includes an outwardly facing pocket 144 in the wall thereof in which is pivotally housed one or more dogs 150. Dog 150 is pivotably mounted on a pivot pin 152 and is sized to be received within pocket 144. Dog 150 has a radially extending outer and engaged position extending through a window portion 146 of sleeve 138 as shown in Figure 12B. In the outer and engaged position, dog 150 rests and is supported by the bottom 148 of pocket 144 and the lower end of window 146. As shown in Figure 12B, in the outer and engaged position of dog 150, dog 150 extends below the lower terminal end of lower slip 14 so as to ensure the retainage of slip 14 around the lower outer sleeve 100.

A cap 154 is threaded at 156 to the lower end of inner lower mandrel 96 to close hydraulic passageway 118 and to retain dog collar 114 within lower outer sleeve 100. Cap 154 may also include a bore extension 158 and a closure cap 160 for access to hydraulic passageway 118.

As shown in Figures 12A and B, reference member 10b is mounted around setting member 90 with dog 150 supporting lower slip 14. The orientation member 16 extending from upper slip 12 receives an orientation key 72 on the lower end of landing sub 86 for orienting the well tool. An annular stop shoulder 162 is provided on stinger 85 of sub 86 so as to provide a downwardly facing stop surface on the upper apex 68 of orientation member 16.

Referring now to Figures 16-19, there is shown the staged setting operation of reference member 10b and the releasing of setting member 90. Although the actuation of reference member 10b is described as a hydraulic actuation, it should be appreciated that there are other methods of actuation other than hydraulic actuation such as mechanical actuation. One type of mechanical actuation includes releasing a trigger on a pre-energized actuator which then causes slips 12, 14 to expand into biting engagement with casing 28.

Referring now to Figure 16, for the hydraulic actuation of upper and lower slips 12, 14, fluid pressure is applied through hydraulic passageway 118 from the surface. This fluid pressure is applied through upper and lower hydraulic ports 124, 126 and into that portion of cylinders 106, 110 between the heads of upper and lower pistons 108, 112 and the full diameter portion 92 of mandrel 91. As shown in Figure 6, this fluid pressure causes pistons 108, 112 to move away from annular portion 92 of mandrel 91. Since pistons 108, 112 are attached to upper and lower cones 18, 20 by shear members 56, 58, respectively, as pistons 108, 112 move, so do upper and lower cones 18, 20. Thus, upper and lower pistons 108, 112 move upwardly and downwardly, respectively, such that upper and lower cones 18, 20 cause wedge surfaces 60, 62 to cam upper and lower slips 12, 14 outwardly into engagement with casing 28. As upper and lower cones 18, 20 separate, ratchet ring 22 maintains their separation by means of engagement of ratchet teeth 41 and wickers 40.

Referring now to Figure 17, all of the load caused by the hydraulic actuation of upper and lower slips 12, 14 is carried through shear members 56, 58. Upon upper and lower slips 12, 14 reaching through outermost biting engagement with casing 28, further hydraulic pressure is applied causing shear members 56, 58 to reach their shear value and shear the connections between the setting member 90 and reference member 10b. Members 56, 58 separate into two components 56A, 56B and 58A, 58B, respectively, following shearing operation. Upper piston 108 continues its upward movement until it engages the lower end of landing sub 86 and the lower piston 112 continues its downward movement until it engages dog collar 114.

Referring now to Figure 18, after shear connections 56, 58 are sheared and pistons 108, 112 reach the limits of their travel, further hydraulic pressure is applied causing lower piston 112 to apply additional force on dog collar 114 until that force causes the shear connection 140, best shown in Figure 2B, to shear allowing a further downward movement of lower piston 112 thereby moving dog collar 114 downwardly against lower cap 154. Dog collar 114 serves as a bulkhead member. As dog collar 114 moves downwardly, the lower end 164 of window 146 in sleeve 100 causes dog 150 to pivot inwardly into pocket 144. As dog 150 is cammed to rotate upwardly and inwardly in a clockwise direction, it folds inwardly to clear the lower end of slip 14 and cone 20.

Referring now to Figure 19, once dog 150 is rotated inwardly, setting member 90 is now disconnected from reference member 10b. The setting member 90 may now pass through bore 80 of reference member 10b and be retrieved. Since dog 150 merely holds lower slip 14 onto reference member 10b, once lower slip 14 is expanded and bites into casing 28, dog 150 is no longer required since dog 150 holds no load after slip 14 bites into casing 28.



It is preferred that the reference member 10 be permanently installed prior to the initial drilling operation in the cased borehole 30, thus becoming the universal reference for all subsequent drilling operations. The location of all subsequent drilling operations then becomes relative to the permanent reference point provided by the reference member 10. The reference member 10 becomes a marker and an orienting locator for subsequently used well tools.

Typically, the reference member 10 is less than a few hundred feet from the last well operation and thus any deviation from reference member 10 is small compared to the deviation from the surface. The use of the reference member 10 as the reference point for all drilling operations allows those drilling operations to be precisely located relative to each other as well as relative to the reference member 10. Thus, the reference member 10 does not determine absolute depth from the surface but relative depth.

Once the reference member 10 is set, all subsequent drilling operations are performed relative to that fixed depth within the cased borehole 30. For example, in the placement of individual lateral boreholes, each of the lateral boreholes is located relative to the reference member 10. In particular, the location of the individual lateral boreholes is not determined relative to the surface. As a further example, the assemblies for performing individual drilling operations are landed and oriented with respect to the reference member 10. Since each of these assemblies has a known length, the individual drilling operations performed by these assemblies is known and thus the absolute distance between the reference member 10 and an individual lateral borehole is also known. Thus, the reference member is used to space out all future drilling operations and thus conduct those operations at a specific location.

It should be appreciated that any well tool may be disposed and oriented on reference member 10. By way of example, typical well tools include a setting tool, hinge connector, whipstock, latch mechanism, or other commonly used well tools for drilling operations. The reference member 10 becomes a marker and an orienting locator for subsequently used well tools.

It is preferred that the reference member 10 be installed in one trip into the borehole. A trip is defined as lowering a string of pipe or wireline into the borehole and subsequently retrieving the string of pipe or wireline from the borehole. A trip may be defined as a tubing conveyed trip where the well tool is lowered or run into the well on a pipe string. It should be appreciated that the pipe string may include casing, tubing, drill pipe or coiled tubing. A wireline trip includes lowering and retrieving a well tool on a wireline. Typically a wireline trip into the hole is preferred over a tubing conveyed trip because it requires less time and expense.

The reference member 10 not only locates the well tool at a known depth but also orients subsequently installed well tools within the borehole. In particular, the orienting surface on the orientation member guides the well tool to a known orientation within the borehole 30. It should be appreciated that the orienting member of the reference member 10 may include various types of orienting surfaces including mating mule shoes or an orienting surface with slot or an orientation key. It should further be appreciated that the orientation member of reference member 10 may be any device which will allow alignment with a member stabbing into reference member 10.

Although the reference member 10 has been described for use both as a depth locator and angular orienter, it should be appreciated that the angular orientor feature may not be required in certain operations such that the reference member 10 would not include the orientation member, for example, but may only include an upwardly facing annular shoulder to engage a similar shoulder on a landing sub so as to locate the well tool at a predetermined depth within the well bore. For example, note annular shoulder 162 on landing sub 86. Where the reference member is only used to locate a predetermined depth in the well, the reference member may be described as an insertable no-go member. If orientation were later required, a well tool may be landed on the insertable reference member. A survey tool may then be used to orient the well tool and landing sub to determine the proper orientation within the well bore for a packer or anchor, for example, which is then set in the casing. The insertable reference member again would not serve as either a packer or anchor and would only prevent a well tool from passing further into the well bore. It would also not prevent any rotation of the well tool.

It should be appreciated that there are many orientating tools and methods well known in the art for determining the orientation of reference member 10. Such prior art orientating tools and methods may be used with the well reference apparatus and method of the present invention. It is preferred that the reference member be oriented in a preferred orientation within the cased borehole. Thus, it is preferred that once the reference member is located at a preferred depth within the cased borehole, that the orienting tool be used to determine the orientation of the reference member 10. For example, in a horizontal well, it is preferred that the reference member be located on the high side of the borehole and project downwardly so as to avoid becoming an interference with any tools which are run through the through bore of the anchor member.

Various orienting tools and methods may be used to determine the orientation of the reference member 10. One common method is the use of a measurement while drilling ("MWD") tool. Various types of MWD tools are known including, for example, a

magnetometer which determines true north. Typically, a bypass valve is associated with the MWD tool since the MWD tool typically requires fluid flow for operation. Fluid flows through the MWD tool and then back to the surface through the bypass valve allowing the tool to conduct a survey and determine its orientation within the drill string or cased borehole. Since  
5 the orientation of the MWD tool is known with respect to the reference member 10, a determination of the orientation of the MWD tool also provides the orientation of the reference member 10.

In one preferred method of the well reference apparatus and method of the present invention, the reference member 10 is disposed on the end of a pipe string with an MWD collar  
10 disposed on the pipe string above the reference member 10. In operation, the assembly is lowered into the borehole on the pipe string. Once the preferred depth is attained, the MWD is activated to determine the orientation of the reference member 10. If the reference member 10 is not oriented in the preferred orientation, the pipe string is rotated to align the reference member in the preferred orientation. This process may be repeated for further corrective action  
15 and to verify the proper orientation of the reference member 10. Upon achieving the proper orientation of the reference member 10, the reference member 10 is set within the borehole 30 and the pipe string disconnected from the reference member 10 and retrieved. It should be appreciated that the pipe string may also include a well tool for performing a well operation in the borehole 30. The well tool would preferably be disposed between the MWD collar and the  
20 reference member 10.

In an alternative preferred method, the well reference apparatus and method includes an assembly of the reference member 10 on the lower end of a pipe string. The assembly is lowered into the well until the desired depth is achieved. An orienting tool, such as wireline gyro is lowered through the bore of the pipe string and oriented and set within the reference  
25 member 10. The orienting tool determines the orientation of the reference member 10. If the reference member 10 does not have the desired orientation, the pipe string is rotated to the desired orientation of the reference member 10. The orienting tool may be used to take further corrective action or to verify the orientation of the reference member 10. Once the orientation of the reference member has been achieved, the wireline orienting tool is retrieved from the  
30 well. It can be appreciated by one skilled in the art that a well tool for a well operation may also be disposed in the pipe string. It can be seen that this embodiment requires both a tubing conveyed trip and a wireline trip into the well.

It should be appreciated, however, that the reference member 10 may be set within the cased borehole 28 and then its orientation determined by an appropriate orientation measuring

tool. For example, the reference member 10 may be lowered into the well on a wireline and wireline set within the cased borehole. A wireline gyro may then be lowered into the borehole and orientingly received by the reference member 10 to determine the actual orientation of the reference member within the borehole. The orientation member on the reference member 10  
5 receives landing sub 86 with orientation key 72 connected to a wireline gyro or other orientation device. The orientation member orients the gyro in a predetermined orientation such that upon the gyro determining its orientation within the cased borehole 28, the orientation of the reference member 10 is also known. The MWD tool is preferred over the wireline gyro in a horizontal borehole where there is no gravity to assist the gyro to pass down through the  
10 cased borehole 28. As can be appreciated, this requires an additional trip into the well and may or may not achieve a desired angular orientation of the reference member within the borehole.

Preferably, the setting tool is assembled onto the reference member 10 at the surface. The setting tool is connected to the landing sub 86 with an orientation surface which engages the orientation surface on the orientation member on the reference member 10. This  
15 engagement aligns the setting tool with the reference member 10 for orienting and mating the orientation surface on the reference member 10. Thus, the setting tool is oriented in a specific manner with respect to the reference member 10 prior to being lowered into the well bore 30.

Although not preferred, it should be appreciated that the setting tool may remain attached to the reference member. However, to achieve the full advantages of the present  
20 invention, if the setting tool is to remain attached to the reference member 10, it is preferred that the setting tool include a through bore which does not restrict the passage of production fluids and well tools.

It should further be appreciated that the reference member 10 may be mounted below a retrievable packer to form a two-stage packer. The upper stage of the packer with the sealing  
25 elements may be removed allowing the reference member to remain in the borehole.

It should also be appreciated that the reference member 10 may be adapted to also serve as an anchor or as a packer. See U.S. Provisional Application Serial No. 60/134,799, filed May 19, 1999 and entitled "Well Reference Apparatus and Method," hereby incorporated herein by  
reference.

30 It should be appreciated that the well reference apparatus and method may be used with many types of well tools used for accomplishing a drilling operation in a well and in particular for multi-lateral drilling operations. For example, such well tools may include a whipstock, a deflector, a sleeve, a junction sleeve, a multi-lateral liner, a liner, a spacer sub, an orientation

device, such as an MWD or wireline gyro, or any other tool useful in drilling and completion operations.

The well reference apparatus and method is useful in the drilling of boreholes in new and existing wells and particularly is useful in the drilling of multi-lateral wells. Multi-lateral wells are typically drilled through an existing cased borehole where a lateral borehole is sidetracked through a window cut in the casing and then into the earthen formation. Multi-lateral wells include a plurality of lateral boreholes sidetracked through an existing borehole. The preferred embodiment will now be described for use in milling a window in the cased borehole and drilling a lateral borehole. It should be appreciated that this method is only one example of the well operations which may be conducted with the well reference apparatus and method of the present invention.

Referring now to Figures 20-24, the well reference apparatus and method of the present invention has particular application in drilling operations for the drilling of multiple lateral boreholes from an existing cased well. It should be appreciated that for reasons of clarity and simplicity not all details are shown in Figures 20-24, and details are only shown where necessary or helpful to an understanding of the invention. Standard fluid sealing techniques, such as the use of annular O-ring seals and threaded connections may be depicted but not described in detail herein, as such techniques are well known in the art. As such construction details are not important to operation of the invention, and are well understood by those of skill in the art, they will not be discussed here.

Referring now to Figures 20A-C, there is shown one preferred assembly 200 of the well reference apparatus and method disposed within an existing borehole 202 cased with casing 204. The cased borehole 202 passes through a formation 206. The assembly 200 includes reference member 10, a setting tool, a landing sub 86, a splined sub 166, a retrievable packer or anchor 170, a debris barrier 168 and a whipstock 180. The splined sub 166 orients the landing sub 86 with the packer or anchor 170. Typically a packer will be used rather than an anchor. Retrievable packer 170 is a standard retrievable packer such as that manufactured by Smith International, Inc. It should be appreciated that a retrievable packer 170 includes a packing element 172, one or more slips 174, and its own setting mechanism 176. Whipstock 180 is a standard whipstock such as the track master whipstock manufactured by Smith International, Inc. Whipstock 180 includes a guide surface 178 facing a predetermined direction 182.

In a one trip system, the assembly 200 further includes a plurality of mills, including a window mill 184 which is releasably attached at 208 to the upper end 210 of whipstock 180 and one or more additional mills 186. Mills 184, 186 may be a track master mill manufactured

by Smith International, Inc. The assembly 200 also includes an MWD collar 188 and a bypass valve 190 disposed above the mills 184, 186. A pipe string 192 supports the assembly 200 and extends to the surface. Further details of the window milling system may be found in U.S. Patents 5,771,972 and 5,894,88, both hereby incorporated herein by reference.

5        Alternatively, it should be appreciated that assembly 200 may be run into the well with a tubing conveyed trip and a wireline trip by replacing the MWD collar 188 with a locator sub for receiving a wireline gyro to determine the orientation of reference member 10.

         It should be appreciated that assembly 200 is assembled with reference member 10, the whipstock face 178, and the MWD collar 188 angularly oriented in a known orientation,  
10        whereby upon the MWD determining its orientation within the borehole 202, the orientation of the reference member 10 and the whipstock face 178 is known. The whipstock face 178 may be aligned with landing sub 86 by splined sub 166. The splines on splined sub 166 also provide for the transmission of torque.

         Referring now to Figures 21A-C, assembly 200 is preferably lowered into the borehole  
15        202 in one trip into the well. Sections of pipe are added to pipe string 192 until reference member 10 reaches the desired depth within borehole 202. This depth may be determined by counting the sections of pipe in the pipe string 192 since each of the pipe sections has a known length. Once the reference member 10 has reached the desired depth, fluid flows down the pipe string 192 with the bypass valve 190 in the open position allowing the sensors within MWD  
20        collar 188 to determine its orientation within borehole 202. If MWD collar 188 includes an accelerometer, the accelerometer will indicate gravitational direction and thus determine the orientation of reference member 10. The pipe string 192 is rotated to adjust the orientation of reference member 10 and the MWD orientation repeated until reference member 10 achieves its preferred and desired orientation within borehole 202. Once the reference member 10 has  
25        achieved its orientation, the bypass valve 190 is closed and the pipe string 192 is pressured up to actuate setting tool 90 to set reference member 10 permanently within the casing 204 of borehole 202. Slips 12, 14 (shown in Figure 1) on reference member 10 grippingly engage the wall of the casing 204 to permanently set reference member 10 within the borehole 202. In the preferred embodiment, anchor 170 is a packer having packing elements 172 which are  
30        compressed to sealingly engage the inner wall of the casing 204. The packing element 172 and the slips 174 or retrievable packer 170 are then set to anchor the whipstock 180 and absorb the compression, tension, and torque applied to the whipstock by the subsequent milling of the window and the drilling of the lateral borehole. An anchor would be used instead of a packer where sealing engagement with the casing is not required.

The well reference member 10 does not include a latching mechanism. When the well reference member 10 is used in milling a window in the casing 28, the well reference member 10 is not latched onto the whipstock and an independent packer or anchor is used to anchor the whipstock and to handle the torque of the milling operation. For example, a weight set packer  
5 may be used on the whipstock and is set after the assembly is depth located and oriented by the well reference member 10. A packer is required where sealing is necessary to seal off the primary borehole.

It may be advantageous to latch the whipstock assembly to the well reference member 10 as well as setting an anchor or packer to serve as an anchor for the milling operation. By  
10 latching onto the well reference member 10, tension may be placed on the work string to ensure that the whipstock assembly has been properly nested, depth located, and oriented in the well reference member 10. If the orientation surfaces are not mating properly, then the collet will not have completely passed through the bore of the well reference member 10 so as to engage the lower end of the well reference member 10 and hold tension. Once the well reference member  
15 10 is properly seated then the anchor or packer is set.

It should be appreciated that a latching assembly may be used to latch a later reentry assembly to the well reference member 10. For example, a big bore packer, an anchor, liner hanger, a marker or some other well tool may be latched onto well reference member 10. The latching assembly may include a latch, *i.e.* a collet, which latches onto the well reference  
20 member 10, much like the setting tools, to serve as an anchor for a subsequent well operation.

Referring now to Figures 22A-C, once packer 170 is set, window mill 184 is released from whipstock 180. Typically, this release is achieved by shearing a shear bolt which connects window mill 184 to the upper end 210 of whipstock 180. It should be appreciated however, that other release means may be provided including a hydraulic release. Upon  
25 detachment of mill 184 from whipstock 180, the pipe string (192 of Figures 11A-C) rotates the mills 184, 186 which are guided by the face 178 of whipstock 180 to cut a window 212 in casing 204. The mills 184, 186 pass through the window 212 and typically drills a rat hole 214 in the formation 206. Typically the pipe string 192 with mills 184, 186 is then retrieved from the borehole 202.

0 It should be appreciated that the mill and drill apparatus of U.S. Patent Application Serial No. 09/042,175 filed March 13, 1998, entitled "Method for Milling Casing and Drilling Formation", hereby incorporated herein by reference, may be used to continue to drill the first lateral borehole 216, best shown in Figure 14A-C. The mill and drill apparatus includes a PDC cutter which is used both as the mill to cut window 212 and the bit to cut lateral borehole 216.

Referring now to Figures 23A-C, the setting mechanism 176 of retrievable packer 170 is actuated to unset slips 174 and disengage packing element 172. Since the retrievable packer 170 is not latched to the reference member 10 after the release of setting member 90, the setting member 90, extension member 86, spline sub 166, retrievable packer 170, debris barrier 168, and whipstock 180 may now be retrieved from the well bore leaving reference member 10 permanently installed within casing 204 at a set depth and particular angular orientation about axis 74. A fishing tool (not shown) may then be lowered for attachment to the upper end 210 of whipstock 180 to remove the assembly and leave reference member 10 permanently within borehole 202.

Referring now to Figures 24A-C, for re-entering the lateral borehole 194 into formation 192, a bottom hole assembly may be run into the wellbore for working on the lateral borehole 194. In this assembly, the whipstock (180 of Figures 23A-C) is replaced with a deflector 196 which is mounted above the debris barrier 168 and retrievable packer 170. The splined sub 166 supports a landing sub or extension member 86 which includes an orientation surface which engages the orientation surface on the orientation member. As orientation surfaces engage, the well tool rotates as it rides downwardly along the orientation surface of the orientation member. Upon seating the orientation surfaces, the face 198 of deflector 196 is properly oriented toward lateral 194 so as to guide a work string into lateral 194 to complete operations in the lateral borehole into the formation 192. A work string is deflected through window 212 by deflector 196 for performing operations in the borehole 216. Once work in lateral borehole 216 has been completed, the work string is retrieved and removed from the boreholes 216 and 202. Upon properly orienting the assembly on reference member 10, the packing element 172 and slips 174 of retrievable packer 170 are set to absorb the impact of the compression, tension, and torsion applied during the operation. The assembly is not latched into reference member 10.

After the setting tool 30 and collets are removed, a reentry assembly with a collet may be lowered through the well reference member 10 with the collet passing through the bore of well reference member 10 to latch onto member 10. The collet first passes through the bore of well reference member 10 in a contracted position and then is expanded to latch onto the lower terminal edge of well reference member 10 much like that shown on the setting tools.

The reentry assembly may be modified to allow for a large bore therethrough for access below the well reference member 10. Excess members on the setting tool are removed and a thinner walled housing is used. The lower nose cap is removed along with the lower power pack. A smaller nose cap may be used and run back in with the reentry assembly. The splined



sub is also used in a subsequent reentry to properly orient the new well tool with respect to the mating orientation surfaces so that the new well tool is properly oriented for the well operation.

Although the operation describes the reference member 10 being run into the borehole 202 with the assembly of the whipstock 180 and mills 184, 186, it should be appreciated that reference member 10 and releasable setting member may be run into the well independently of the other well tools. The reference member 10 would be set at a predetermined depth and orientation for the subsequent well operation. The assembly for the subsequent well operation would include a locator sub 86 with an orientation surface to orientingly engage the orientation member as previously described to properly orient the well tool for this subsequent operation.

10 If it is desirable to have the well tool oriented in a specific direction, such as on the high side or lower side of the well bore, the well tool may be properly oriented with the landing sub 86 at the surface such that upon the landing sub engaging the orientation member of reference member 10, the well tool will be oriented in the preferred direction.

The orientation of reference member 10 is now known for all subsequent drilling operations. Thus, all subsequent well tools may be oriented by reference member 10 and all subsequent drilling operations conducted and spaced out in relation to reference member 10.

A locator sub 86 may be attached to the lower end of a subsequently lowered well tool for installation on reference member 10. The locator sub 86 causes the orientation of the subsequent well tool in a known orientation within the well bore 202 and spaces out the subsequent well tool a known distance with respect to reference member 10.

Referring now to Figures 25A1-3, B1-3, C1-3, and D1-3, there is shown another assembly 400 of the well reference apparatus and method of the present invention. Assembly 400 includes a locator sub 86, a string of spacer subs 402 extending from locator sub 86 to a retrievable anchor 410 connected to the upper end of spacer subs 402, a debris barrier 432, and a whipstock sub 434 with hinge connector 436 connected to another whipstock 440. Mills 450 are attached to the upper end 456 of whipstock 440 by releasable connection 454. A pipe string 464 extends from the mills 450 to the surface. No orientation member is needed in assembly 400 since assembly 400 is oriented by previously set reference member 10.

The objective of assembly 400 is to drill a second lateral borehole 416 located a specific spaced out distance above first lateral borehole 216 of Figures 24A-C). This spaced out distance is determined by knowing the length of each of the members in assembly 400 in relation to reference member 10.

Where the spaced out distance above reference member 10 is a length which allows the assembly of assembly 400 to be made at the surface, the assembly 400 is assembled and the

orientation of the face 442 of whipstock 440 is scribed along the face of the members making up assembly 400 down to locator sub 86. Locator sub 86 is then oriented to properly align with face 442 of whipstock 440 upon installation. Although Figure 25A1-3 appears to illustrate second lateral borehole 416 as being on the opposite side of the cased borehole from first lateral borehole 216, it should be appreciated that the face 442 may be directed in any orientation in borehole 202.

It should also be appreciated that should the spaced out distance of assembly 400 be of a length such that it is not practical to make up the assembly 400 at the surface so as to easily align locator sub 86, the locator sub 86 may be separated into an adjustable connector sub and an orientating latch sub. The orienting latch sub is mounted on the lower end of the spacer subs 402 and the adjustable connector sub is disposed adjacent the whipstock 440, such as between the upper end of the string of spacers 402 and retrievable anchor 410. In this embodiment, the orientation of the lower orientating latch sub would be scribed along the string of spacer subs and then the assembly of the retrievable anchor 410, whipstock 440, and mills 450 are assembled as a unit for connection to the adjustable connector sub at the upper end of spacer sub 402. The adjustable connector sub allows the whip face 442 to then be properly aligned using the scribing on the spacer subs, so as to be aligned with the lower orienting latch sub which will have a known orientation with reference member 10 upon installation.

In operation, assembly 400 is lowered into borehole 202 with locator sub 86 stabbing into reference member 10 to orient assembly 400 in the preferred orientation for the drilling of second lateral borehole 416. Retrievable anchor 410 is then actuated to grippingly engage the casing 204. Retrievable anchor 410 provides support for whipstock 440. Without retrievable anchor 410, the milling and drilling operations on whipstock 440, suspended many feet above reference member 10, causes instability in the milling and drilling operations. The mills 450 are then detached from whipstock 440 and the whipstock face 442 guides and deflects the mills 450 into the casing 204 to mill a second window 412 and drill rat hole 414.

As shown in Figure 25B1-3, the mills 450 are retrieved and a drilling string with a standard bit is lowered into the well to begin the drilling of second lateral borehole 416.

As shown in Figure 25C1-3, a fishing tool 418 may be used to retrieve whipstock 440 and, as shown in Figure 25D1-3, a deflector 380 is attached to a locator sub 86 and spaced out in relation to reference member 10. This assembly is then be lowered into the borehole for orientation on reference member 10.

A work string with standard drill bit may then again be lowered into the well and guided through the window 412 by deflector 380 and into the second lateral borehole 416.

Referring now to Figures 26A1-3, B1-3, and C1-3, there is still another preferred embodiment of the reference well apparatus and method. An assembly 500 includes a locator sub 86, debris barrier 532, and a connector sub 534 for connecting to the lower end of a tieback insert 510. A running tool 512 on the lower end of a drill string 564 is connected to the upper  
5 end of tieback insert 510. One embodiment of tieback insert 510 is shown and described in U.S. Provisional Patent Application Serial No. 60/116,160, filed January 15, 1999, and in U.S. Patent Application Serial No. 09/480,073, filed January 10, 2000 entitled Lateral Well Tie-Back Method and Apparatus, both hereby incorporated herein by reference. Tieback insert 510 includes a main bore 512 and a branch bore 514. Main bore 512 is to be aligned with the  
10 existing borehole 202 while the branch bore 514 is to be aligned with one of the lateral boreholes such as for example lateral borehole 216. For branch bore 514 to be properly aligned with lateral borehole 216, it is necessary that the tieback insert 510 be properly oriented within existing borehole 202.

In operation, the assembly 500 is assembled at the surface with branch bore 514  
15 properly aligned on locator sub 86 so as to be in proper alignment with lateral borehole 216 upon orientation with reference member 10.

The well reference apparatus and method of the present invention may also be used with the system described in U.S. patent application Serial No. 60/247,295, filed November 10, 2000 and entitled Method and Apparatus for Multilateral Completion, hereby incorporated  
20 herein by reference.

In yet another embodiment of the well reference apparatus and method, the reference member 10 may be used in performing operations below reference member 10. Since reference member 10 has a large through bore, access is provided below reference member 10. For example, a liner may be supported from the reference member 10 and include an orientation  
25 slot for engagement with reference member 10 to align the liner. To provide the necessary sealing, a packer would be set above the reference member 10 for packing off the liner hanger with the casing 204. By avoiding the reference member having a mandrel, the bore of the reference member 10 will allow the passage of a ideally sized liner and couplings since the reference member 10 will have a wall thickness equal to or less than that of the wall thickness  
30 of the liner hanger. Thus no bore diameter is lost. The liner hanger is anchored above the reference member. The liner may include a precut window to allow the drilling of another lateral borehole extending through the liner window below reference member 10. Another example includes the support of a tubing string below reference member 10 for the production of a lower producing formation located below reference member 10.

The reference member 10 is relatively thin and may be easily removed from the well if necessary. One method of removing reference member 10 from casing 204 would be through the use of a mill.

In each of the embodiments described above, the well reference member 10 may be released from the casing 28. A release member may be used to release the engagement of the well reference member 10 from the casing 28. For example with respect to well reference member 10a, the release member is attached to one end of the well reference member body 312 thus mounting the well reference member 10a onto the release member. A portion of the release member extends through the well reference member body 312 and that portion has a lower end which extends below the lower end of the well reference member 10. The release member portion also includes a piston member engaging the top of the wedge 320 on the well reference member 10a for driving the wedge 320 out of the engagement with the slot 318 in the well reference member body 312 to release the well reference member 10a from engagement with the casing 28. The release member is removed with the release member engaging the lower end of the well reference member 10a to also remove the well reference member 10a.

The well apparatus and method provides many advantages over the prior art.

The reference member 10 allows the use of a retrievable packer 170 rather than a permanent big bore packer. A retrievable packer has the advantage in that it may be used again thus saving additional expense.

The reference member 10 only need engage the casing a sufficient amount so as to allow the orienting stinger 85 from the landing sub 86 to ride down the inclined surface 66 of orientation member 16 so as to be properly located in depth and properly angularly oriented about the axis.

Another advantage of the reference member is that the bore therethrough approximates the drift diameter and thus is greater than the diameter of the bore of a big bore packer. The larger bore through the reference member permits flowbore operations below the reference member which is a further advantage.

The reference member 10 has a larger bore to allow the passage of larger perforation guns to perforate a formation located below the reference member in the existing borehole. This is also an advantage in new wells where larger perforation guns are used to complete the primary well bore and then used to complete the lateral borehole. Large perforating guns will not pass through a big bore packer.

The reference member provides a substantial economic advantage over the use of a packer or anchor as a reference and orientation device. Since the reference member is not

required to withstand the compression, tension, and torque of the well operation, the construction of the reference member may be of a simple construction, particularly as compared to a packer, and thus be a relatively inexpensive tool. Since the reference member only requires a minimum number of parts, *i.e.* upper and lower slips, upper and lower cones, and an orientation member, a minimum number of parts must remain down hole and also allow the bore through the reference member to be maximized.

The reference member 10 has the further advantage of not requiring a latch. A packer and anchor require that the whipstock be latched to the packer and anchor so as to withstand the compression, tension, and torque of the well operation. Since the packer and anchor are independent of the reference member, the packer and anchor need not be latched to the reference member since the packer and anchor themselves have cones and slips for biting engagement into the casing.

Throughout the detailed description of the preferred embodiments, reference was made to the well reference member 10. This should be understood to also reference other embodiments of the well reference members 10a, 10b. While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

## CLAIMS

## WHAT IS CLAIMED IS:

1. An apparatus serving as a reference within a casing, comprising:
  - a body having an engaging surface and a slot;
  - 5 a wedge member mounted within said slot;
  - said wedge member having a first position within said slot with said engaging surface in a contracted position and a second position within said slot with said engaging surface in an expanded position engaging the casing.
2. The apparatus of claim 1 wherein said body further includes an orientation surface.
- 10 3. The apparatus of claim 2 wherein said orientation surface is a mule shoe surface.
4. The apparatus of claim 1 wherein said body and wedge member are the only two parts making up the apparatus.
5. The apparatus of claim 1 wherein said slot includes a V-shape with said V-shape and wedge member having complimentary tapered surfaces.
- 15 6. The apparatus of claim 5 wherein said surfaces are cut on a radius of said body forming inner and outer edges, said inner edges having a chord which is smaller than a chord formed by said outer edges.
7. The apparatus of claim 1 wherein said body has a thin wall whereby an inside diameter of said body is less than 70% of an inside diameter of the casing.
- 20 8. The apparatus of claim 1 wherein said body is generally tubular and has an inner and outer diameter, said outer diameter in said contracted position being less than said inner diameter in said expanded position.
9. The apparatus of claim 1 wherein said engaging surface is roughened to frictionally engage the casing in said expanded position.
- 25 10. The apparatus of claim 1 wherein said engaging surface has teeth adapted to bite into the casing in said expanded position.
11. The apparatus of claim 10 wherein said teeth are uniformly disposed around said body.
12. The apparatus of claim 1 wherein said slot extends a longitudinal length of said body forming a C-shaped cross sectional body.
- 30 13. The apparatus of claim 1 further including an actuating member for moving said wedge member from said first position to said second position.
14. The apparatus of claim 13 wherein said actuating member engages one end of said body and said wedge member and forces said wedge member into said slot.

15. The apparatus of claim 14 wherein said actuating member is releasably attached to said wedge member.
16. The apparatus of claim 1 wherein said body has first and second ends and further including a setting tool releasably engaging said ends.
- 5 17. An apparatus to locate a well tool in a cased borehole, comprising:  
an engaging member having a longitudinal slot and adapted to engage the cased borehole;  
a wedge member disposed within said slot of said engaging member to force said engaging member against the cased borehole;  
10 an orientation member disposed on said engaging member; and  
said engaging member, wedge member, and orientation member forming a bore through the apparatus.
18. The apparatus of claim 17 wherein the apparatus provides no sealing engagement with the cased borehole.
- 15 19. The apparatus of claim 17 wherein the apparatus has no setting mechanism.
20. The apparatus of claim 17 wherein the apparatus has no latch.
21. The apparatus of claim 17 wherein the cased borehole has a diameter and said bore has a diameter which is at least 70 % of the diameter of the cased borehole.
22. The apparatus of claim 17 wherein said engaging member locates the depth of the well  
20 tool in the cased borehole.
23. The apparatus of claim 17 wherein said orientation member includes a surface which angularly orients the well tool within the cased borehole.
24. A method of installing a reference member in a cased borehole, comprising:  
lowering the reference member into the cased borehole; and  
25 setting the reference member within the cased borehole by driving a wedge into a longitudinal slot in the body of the reference member.
25. The method of claim 24 comprising:  
lowering a reentry tool into the cased borehole; and  
engaging orientation surfaces on the reentry tool and reference member to orient  
30 the reentry tool in the cased borehole.
26. A method for setting a marker in the borehole of a well, comprising:  
running a reference member and orientation tool into the borehole;  
determining the orientation of the reference member;  
rotating the reference member;

repeating the determining and rotating steps until the reference member is properly oriented in the borehole;

permanently setting the reference member within the borehole by expanding the body of the reference member into engagement with the casing;

5           lowering a locator member with well tool into the borehole;

orienting the locator member on an orientation member on the reference member; and

performing a well operation with the well tool.

27. A method for milling a window in a cased wellbore, comprising:

10           disposing into the wellbore a reference member, a reference member setting tool, a sidetracking assembly, whipstock and a mill adapted to mill the window in the cased wellbore;

determining the orientation of the reference member within the cased wellbore;

15           operating the setting tool, either before or after determining the orientation of the reference member, to drive a wedge into a slot in the reference member causing the reference member to engage the cased wellbore; and

milling the window in the cased wellbore.

28. The method of claim 27 wherein the setting tool comprises actuating a piston assembly within the setting tool forcing the wedge member into the slot on the reference member to  
20 expand the reference member so that it engages the cased borehole.

29. The method of claim 27 further comprising

releasing the setting tool from the reference member; and

removing the setting tool from the wellbore.



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FIG. 1

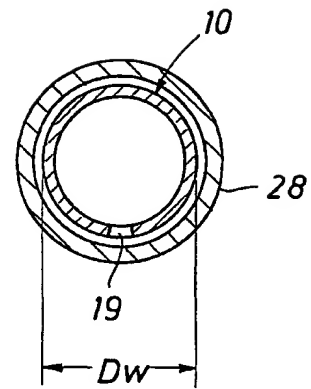
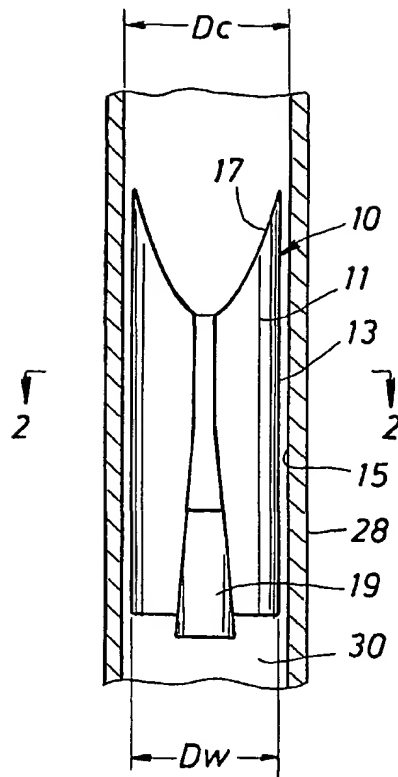


FIG. 2

FIG. 3

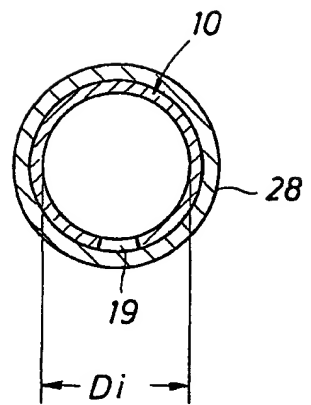
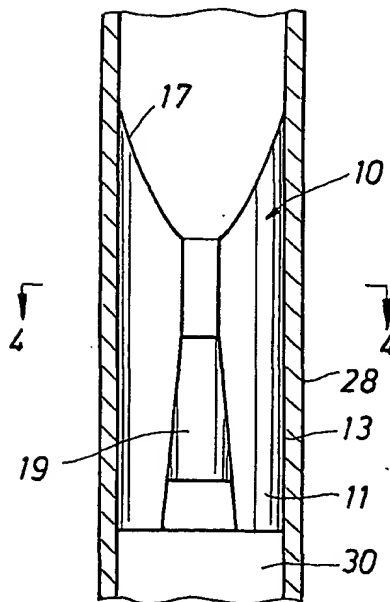


FIG. 4

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FIG. 5

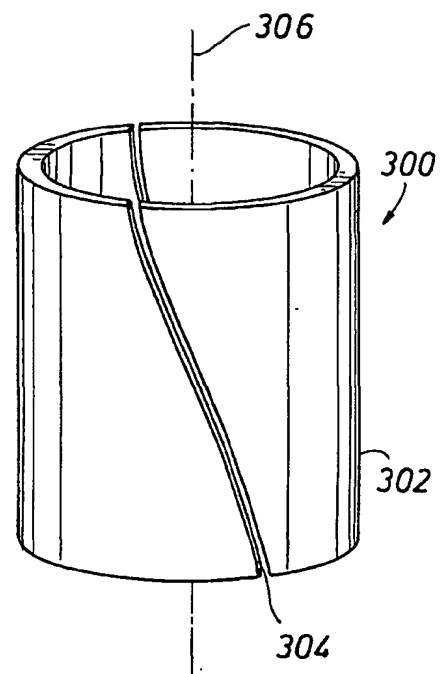
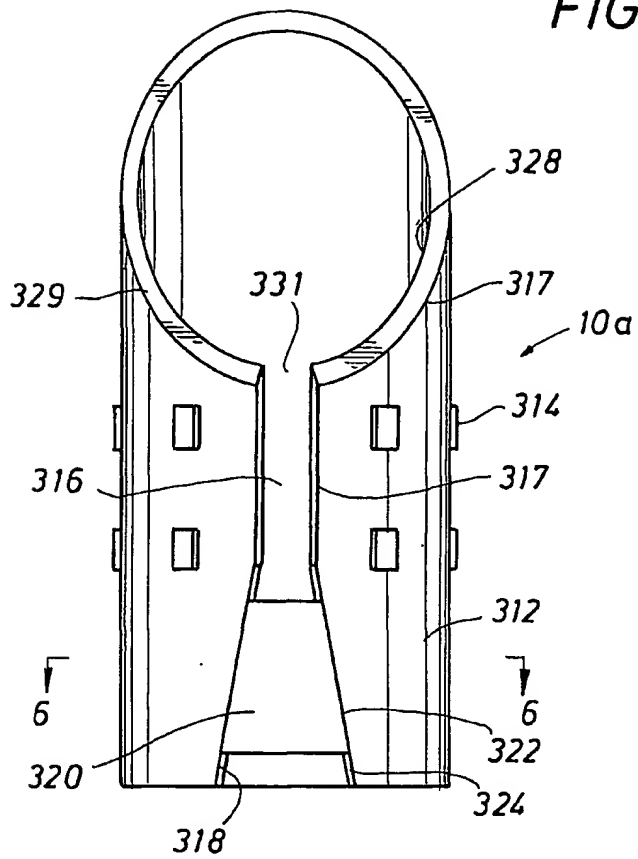


FIG. 7A

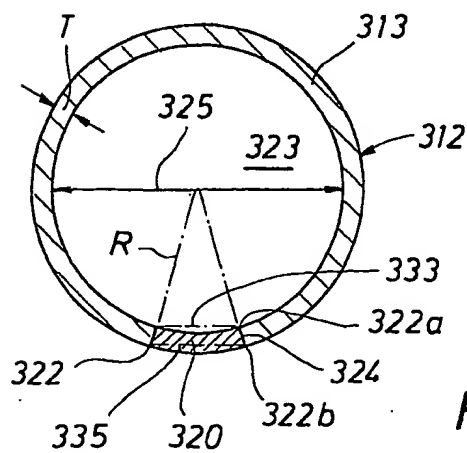


FIG. 6

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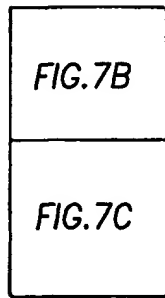
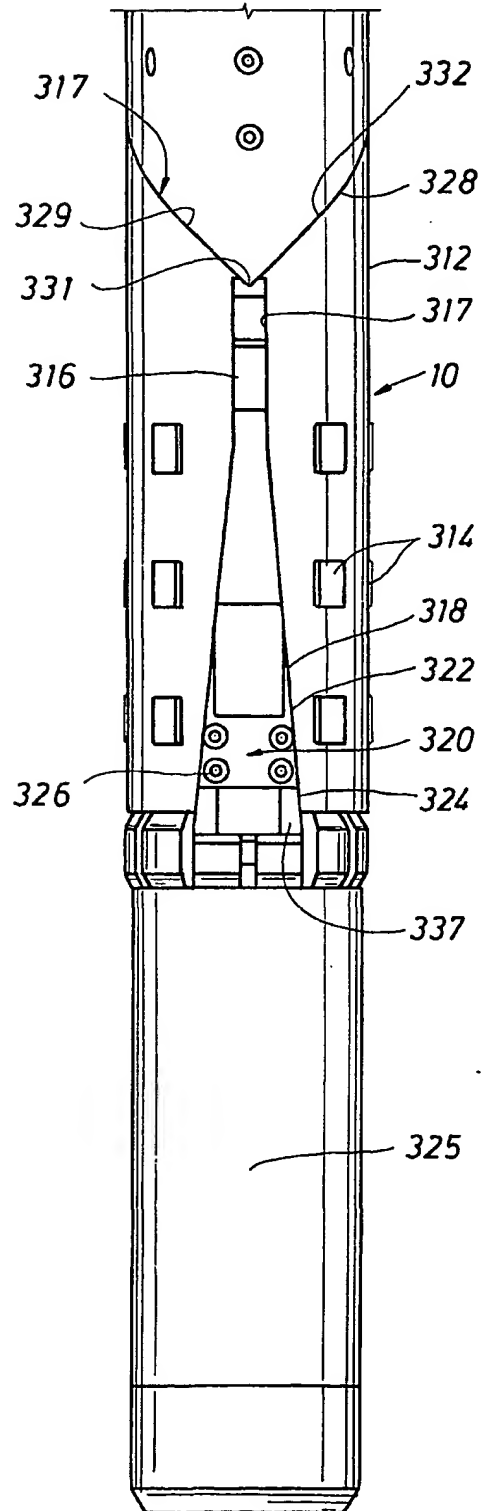
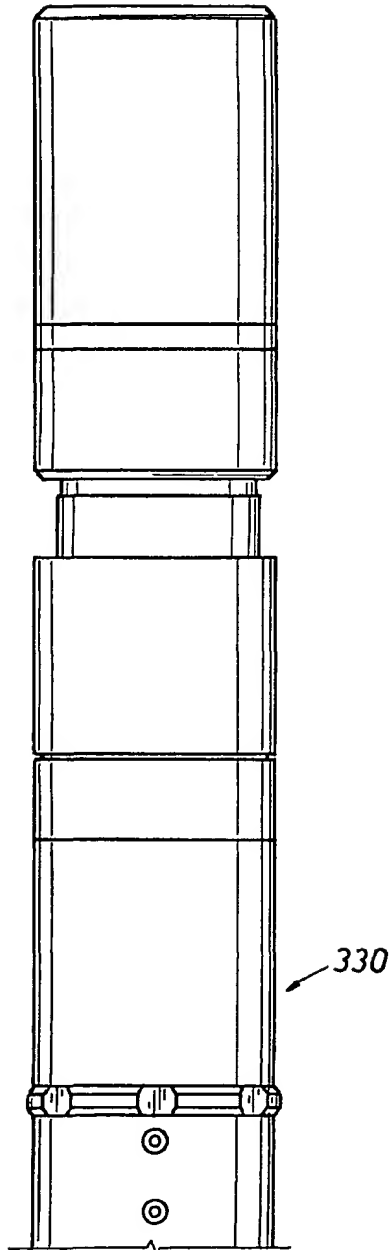


FIG.7

FIG.7C

FIG.7B



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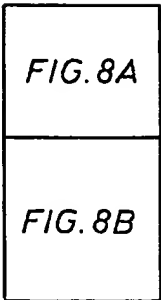
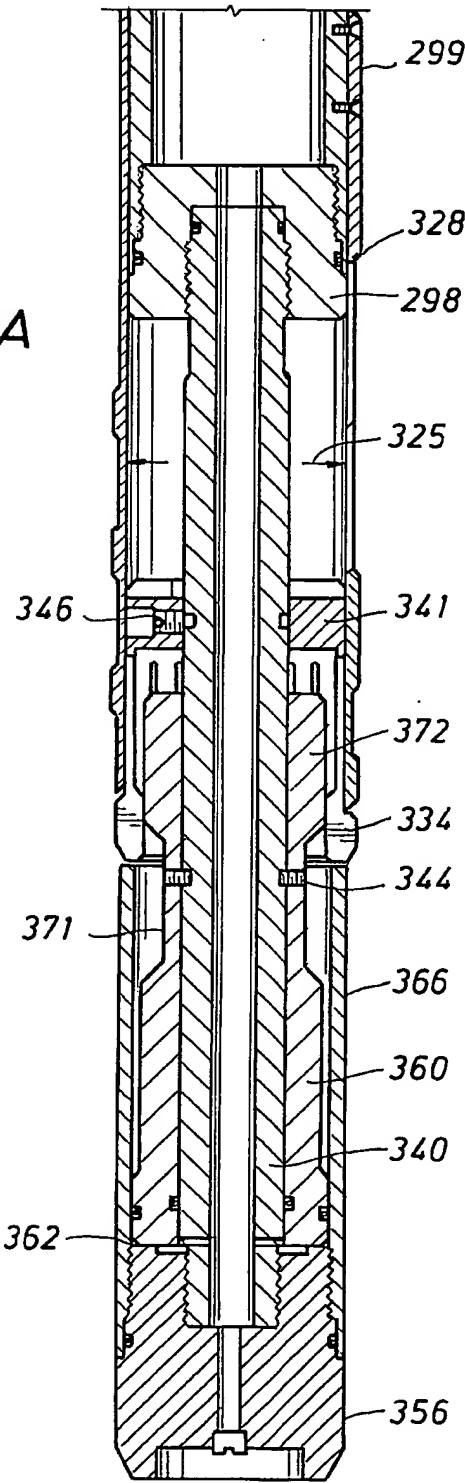
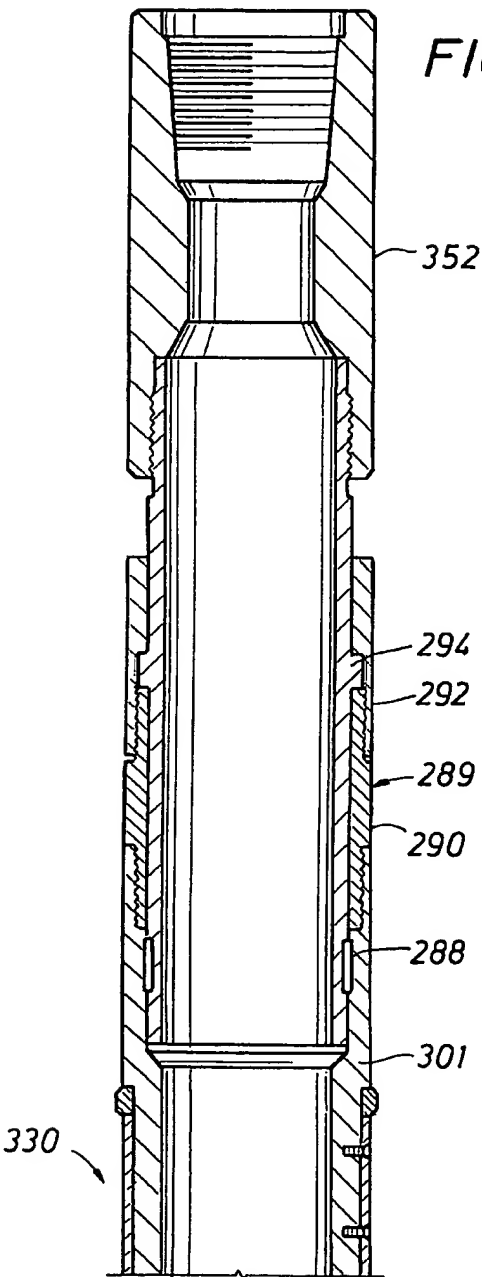


FIG. 8

FIG. 8B



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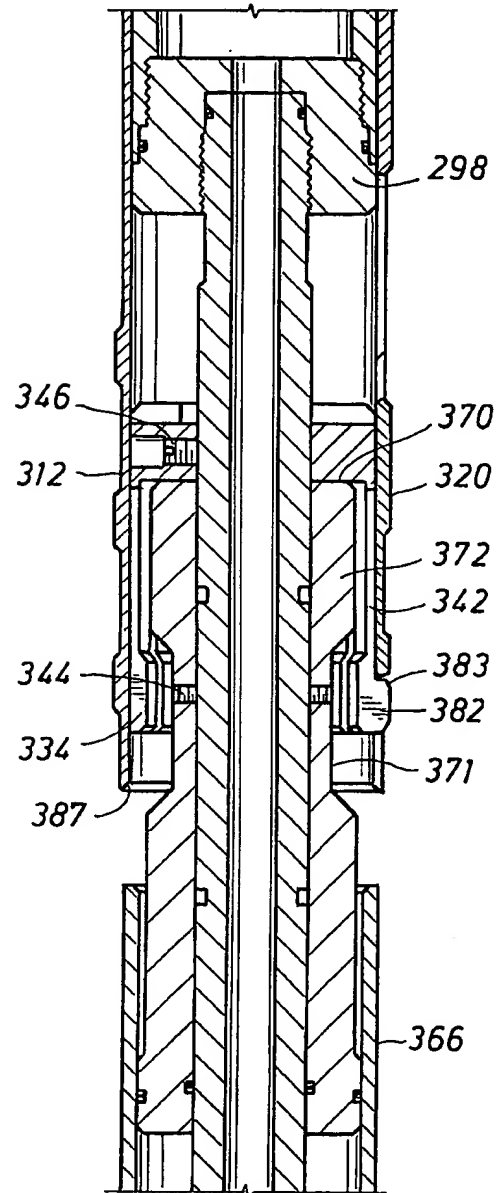
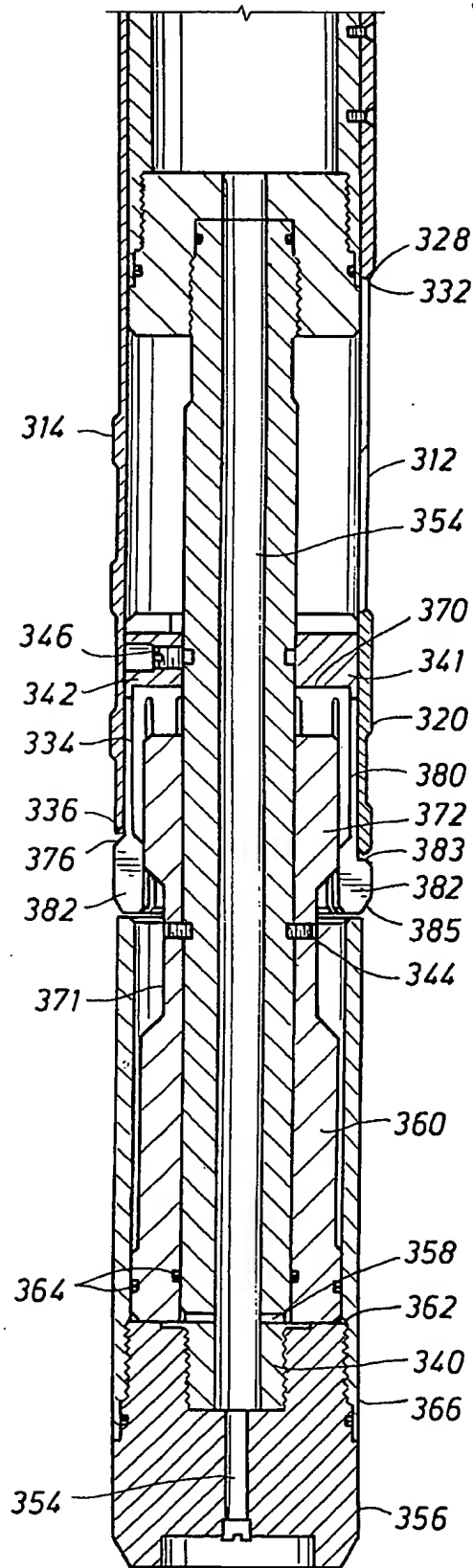


FIG. 10

FIG. 9

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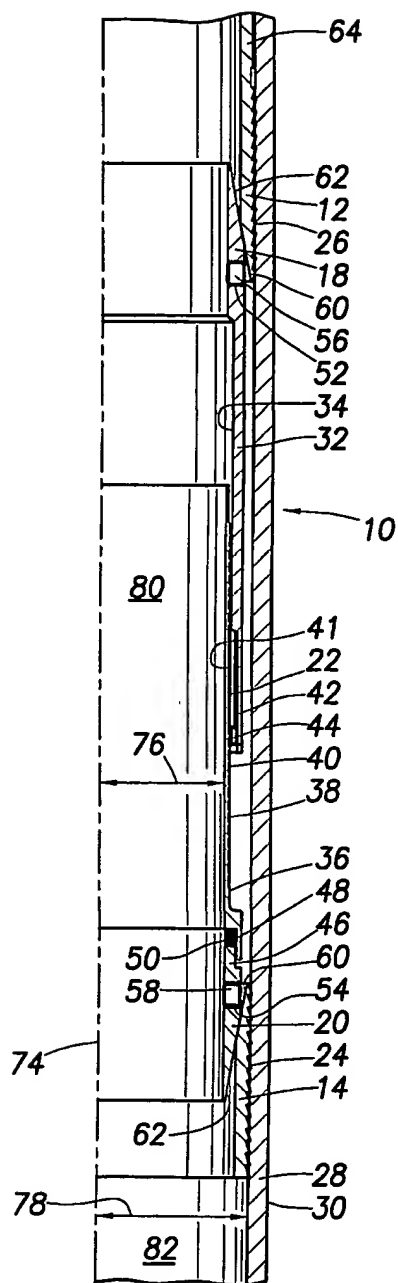


FIG. 11

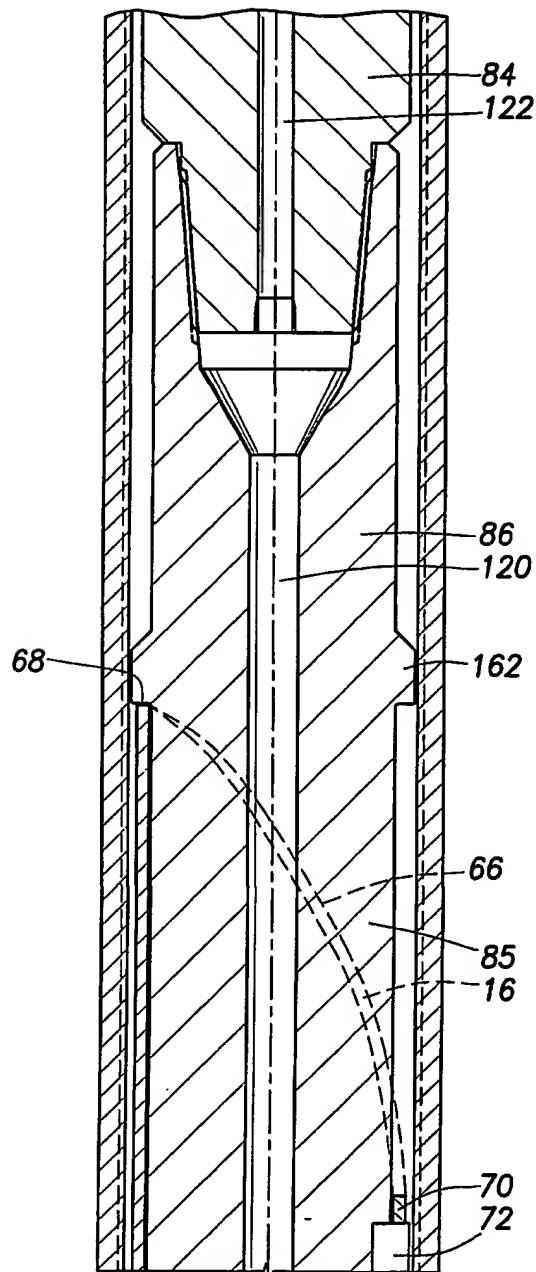
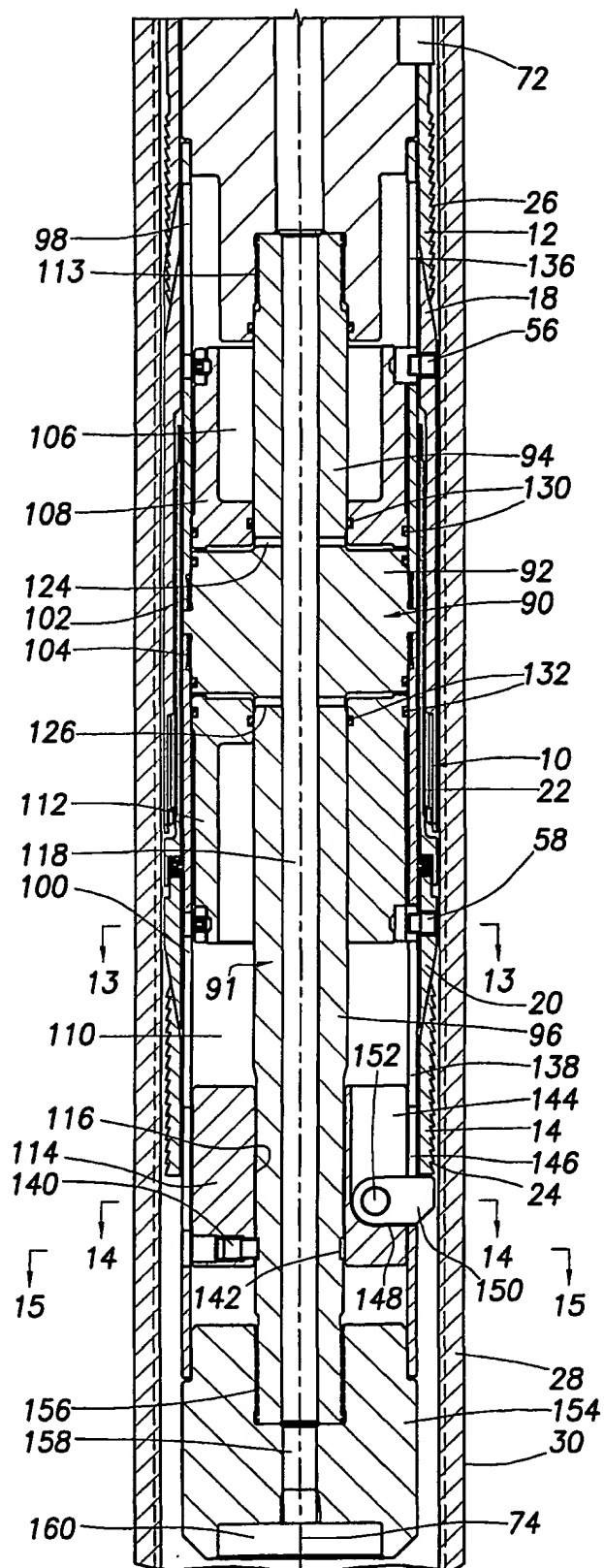


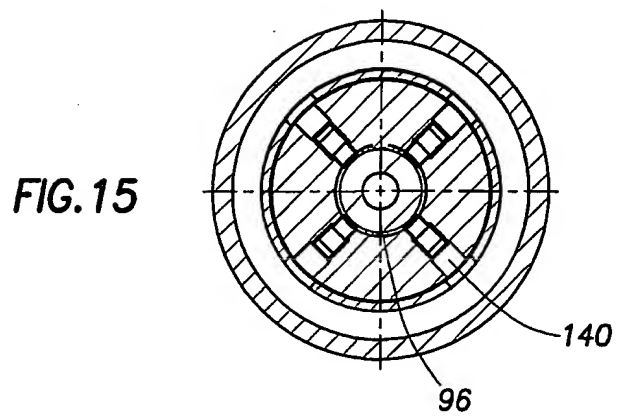
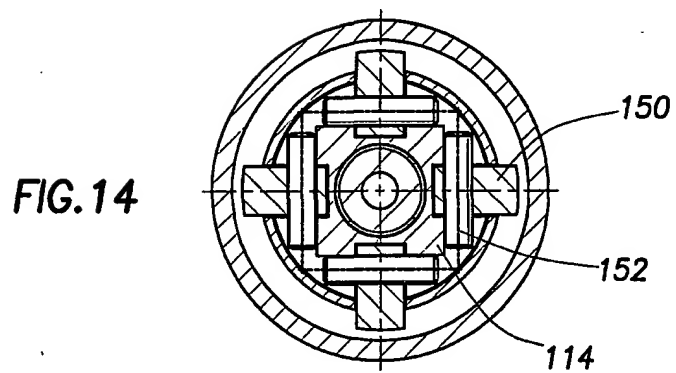
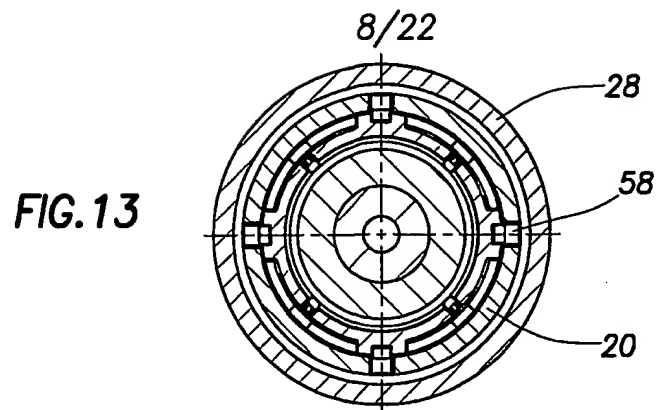
FIG. 12A

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FIG. 12B



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FIG. 16

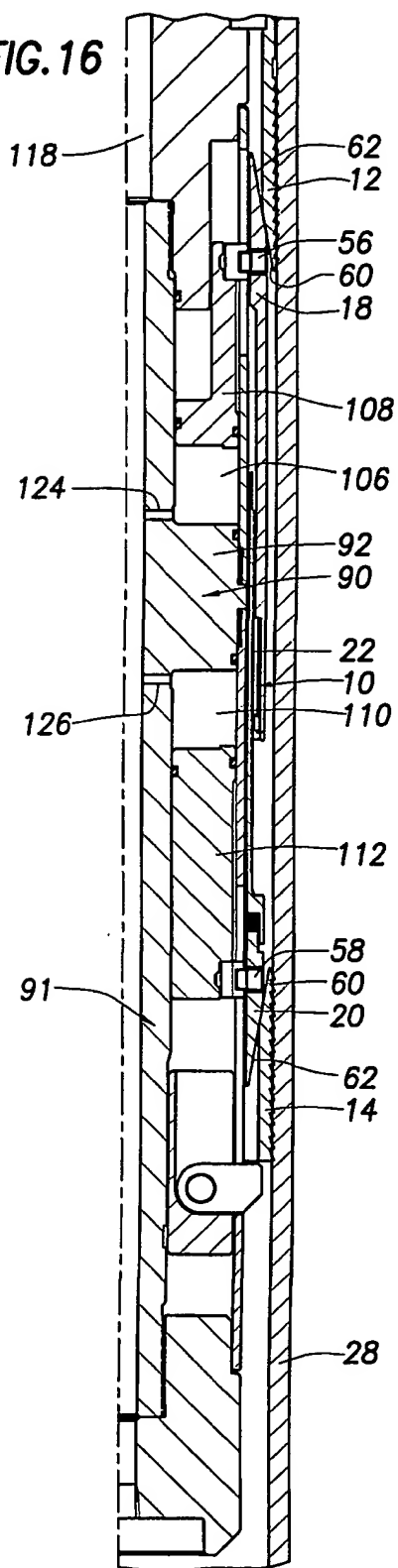


FIG. 17

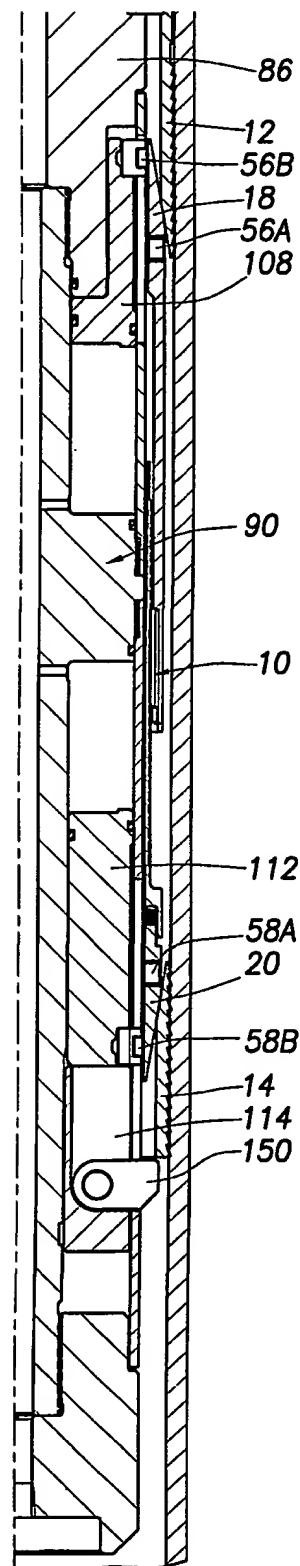
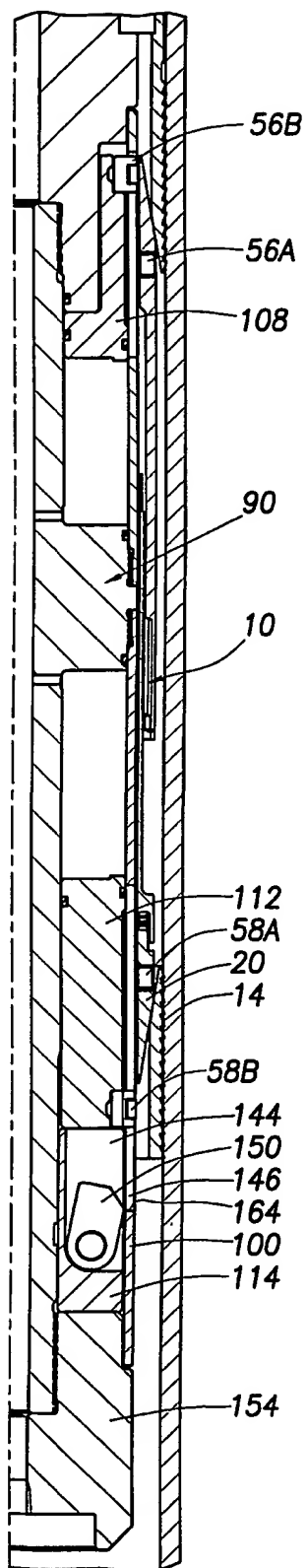
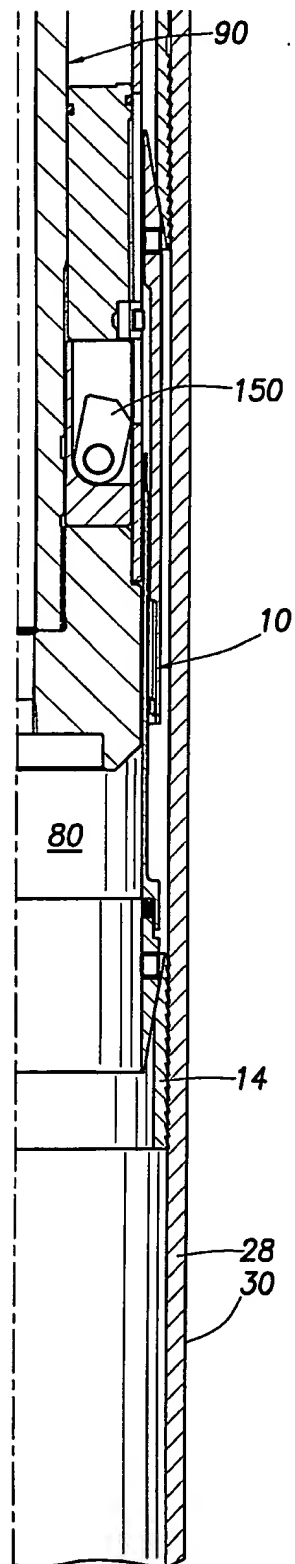


FIG.18



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FIG.19



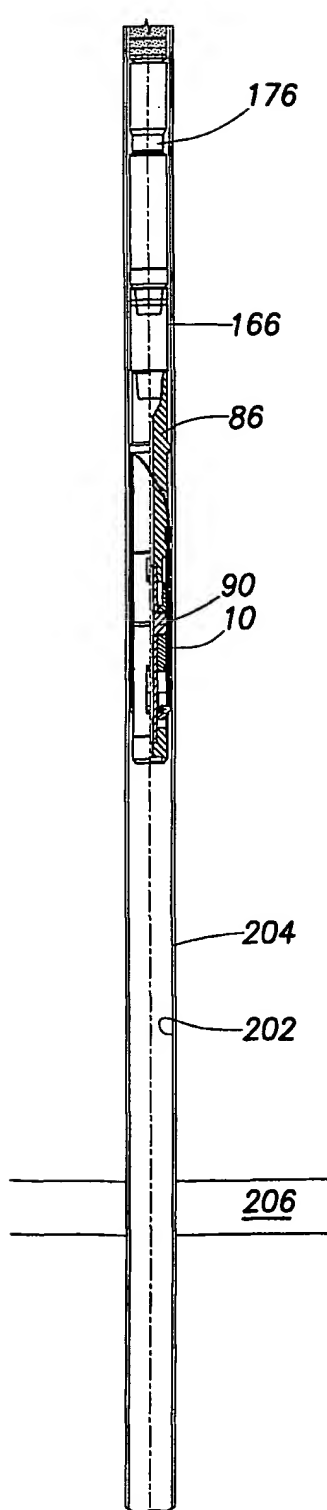


FIG. 20A

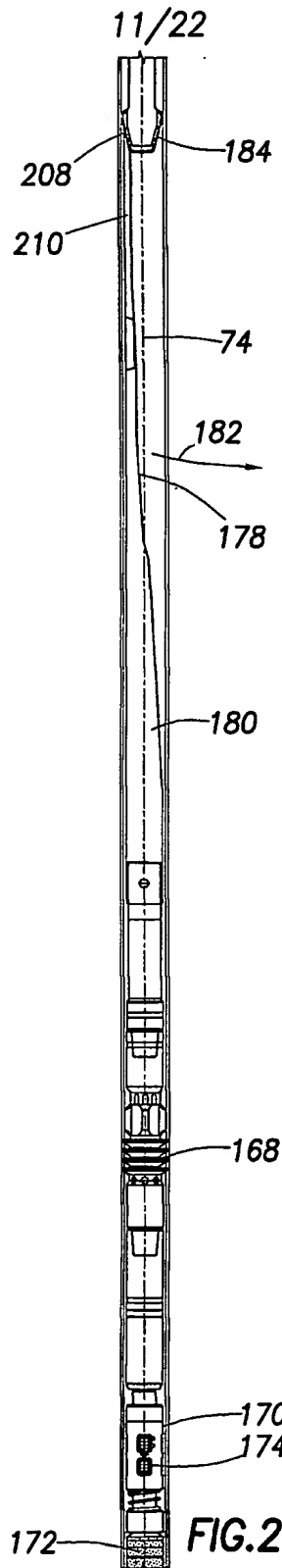


FIG. 20B

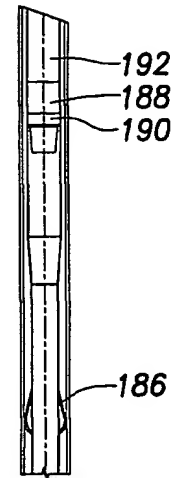


FIG. 20C



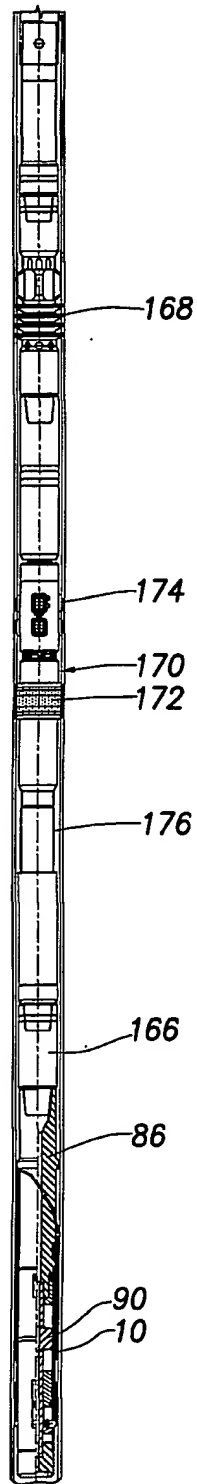


FIG. 21A

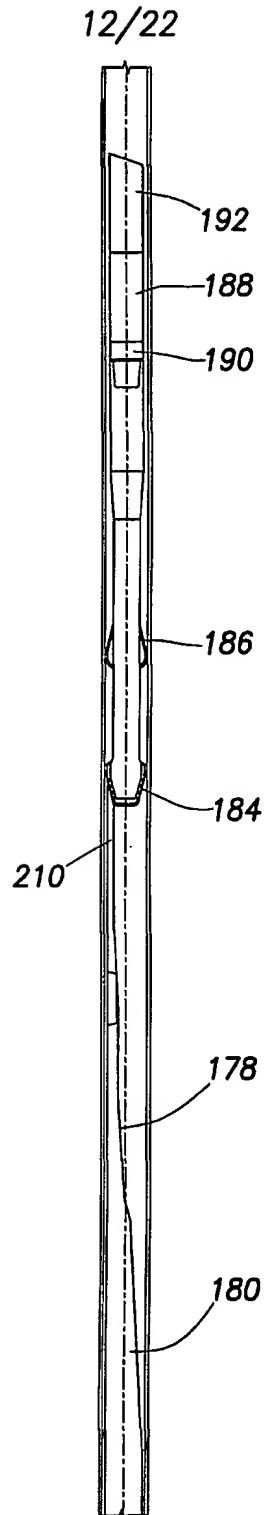


FIG. 21B

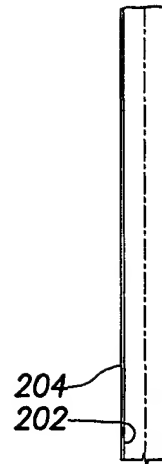


FIG. 21C



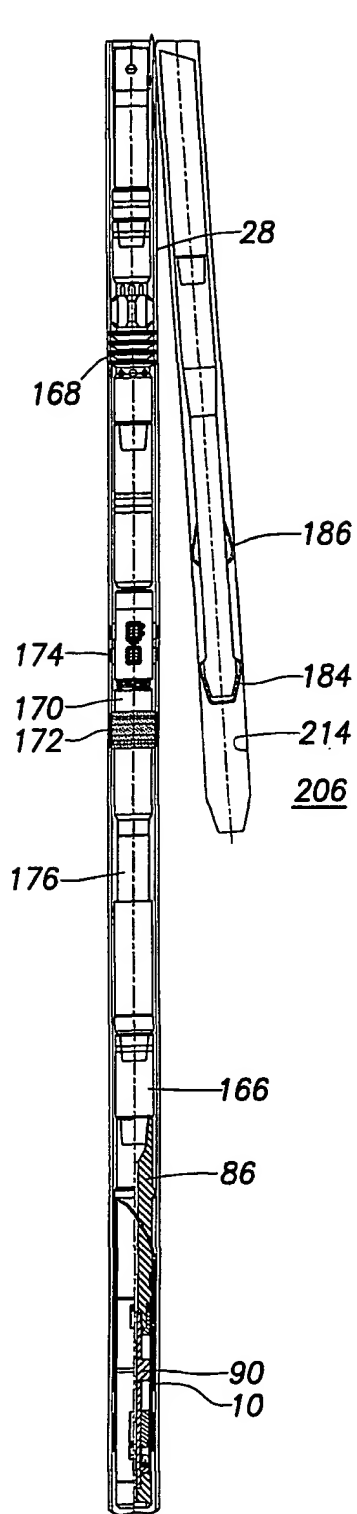


FIG. 22A

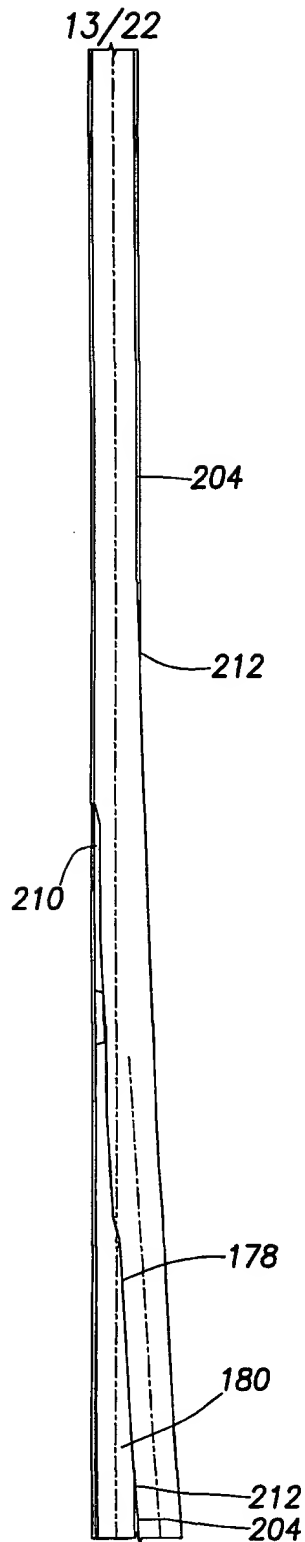


FIG. 22B



FIG. 22C

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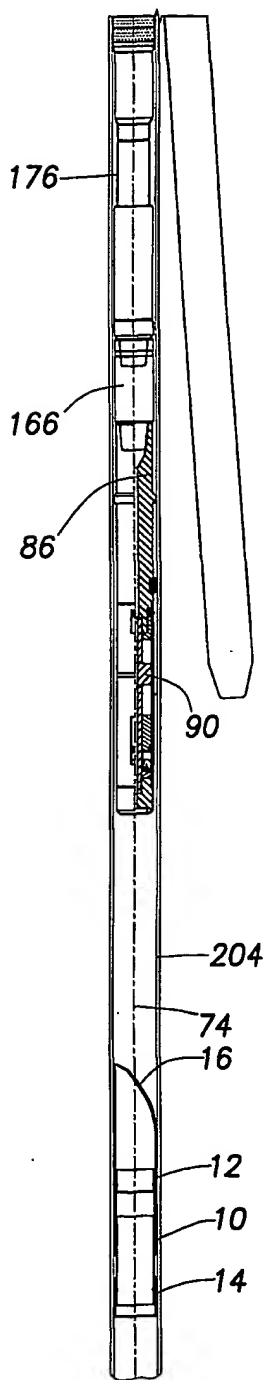


FIG. 23A

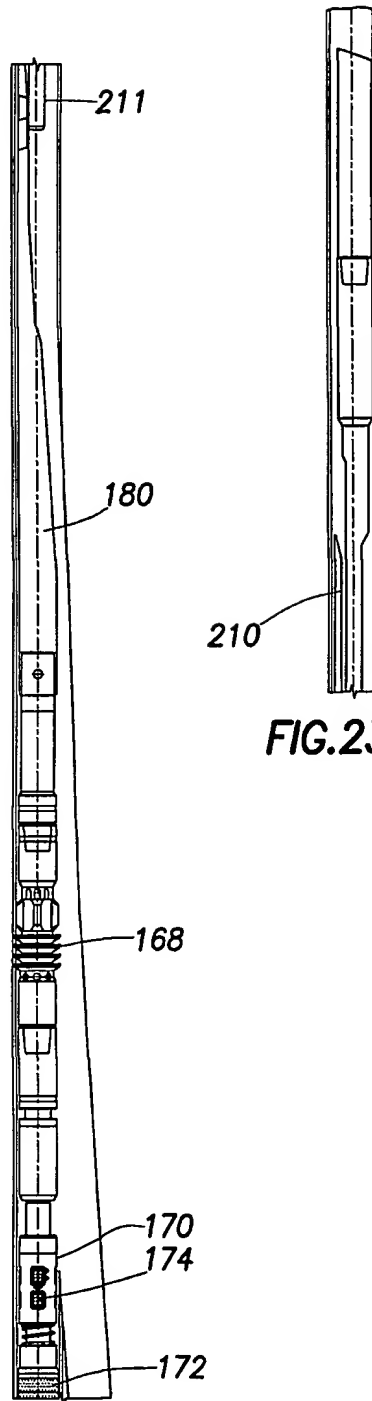


FIG. 23B

FIG. 23C

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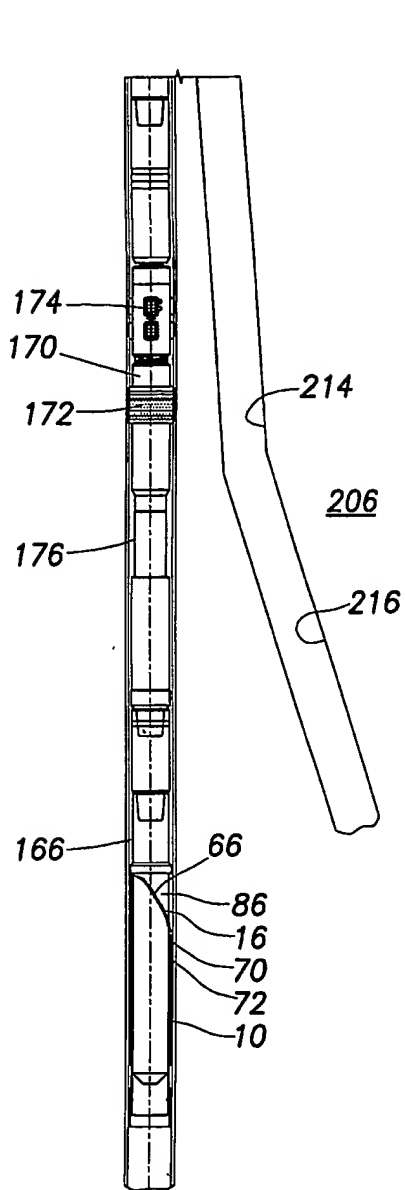


FIG. 24A

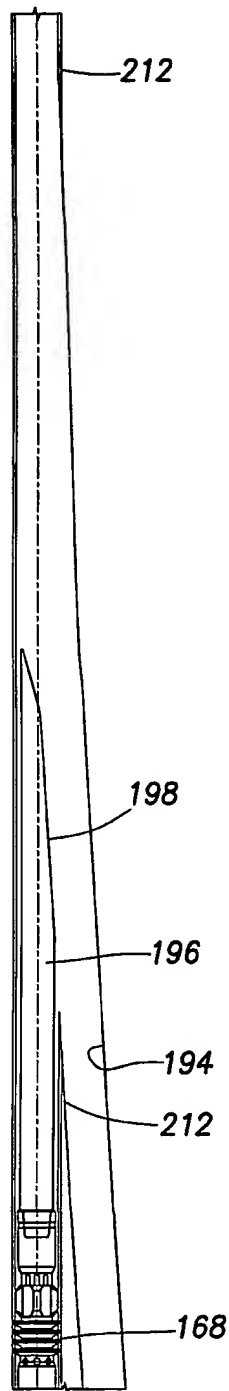


FIG. 24B

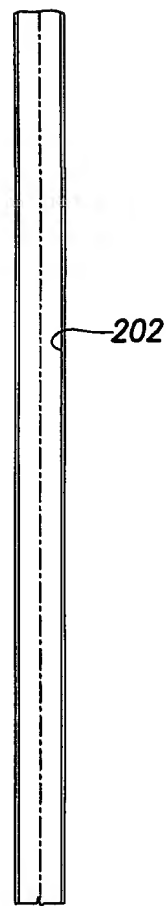
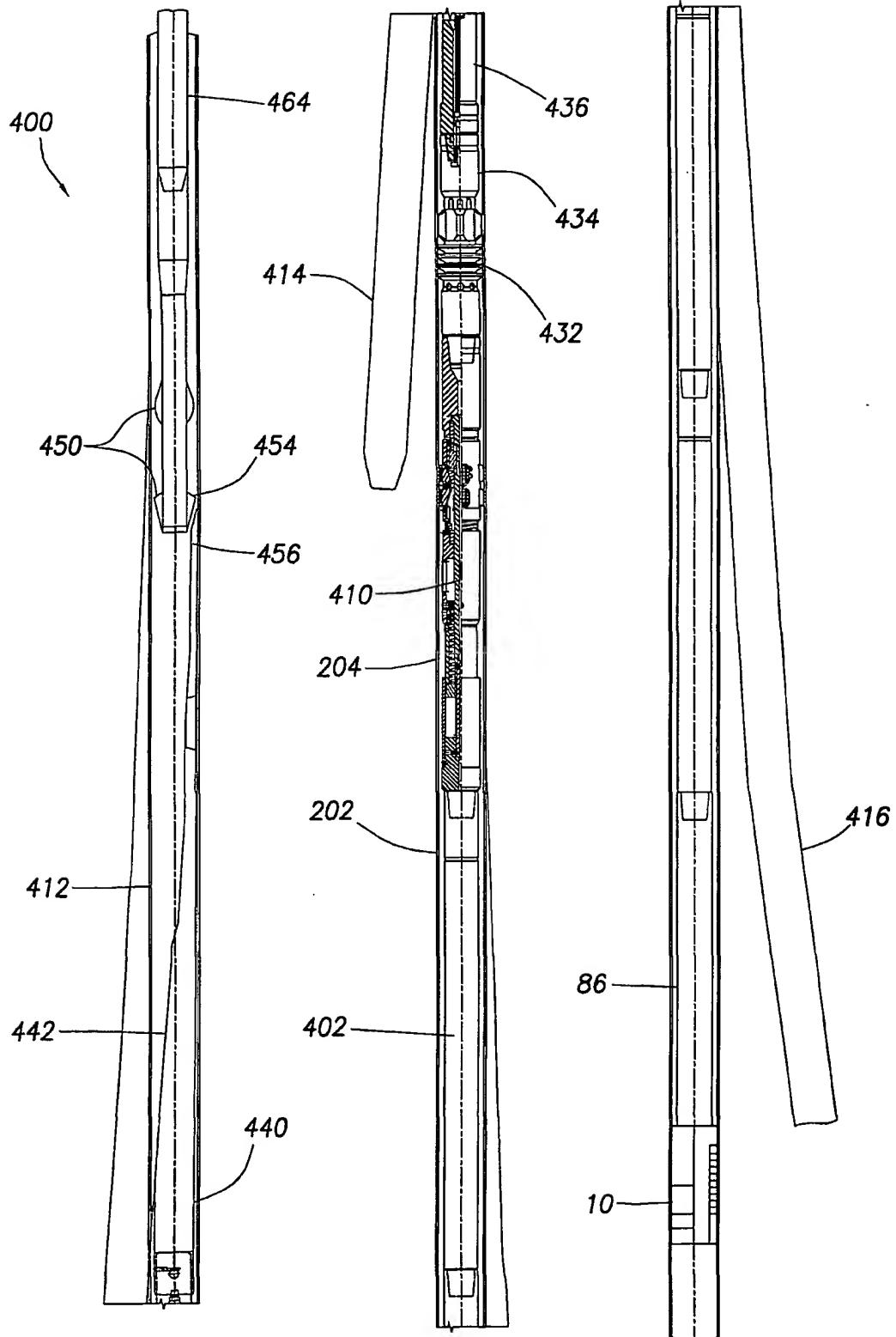


FIG. 24C

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FIG. 25B1

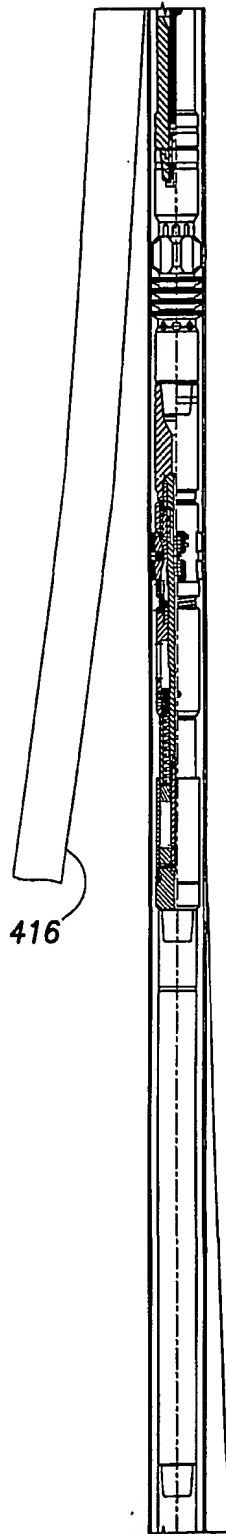


FIG. 25B2

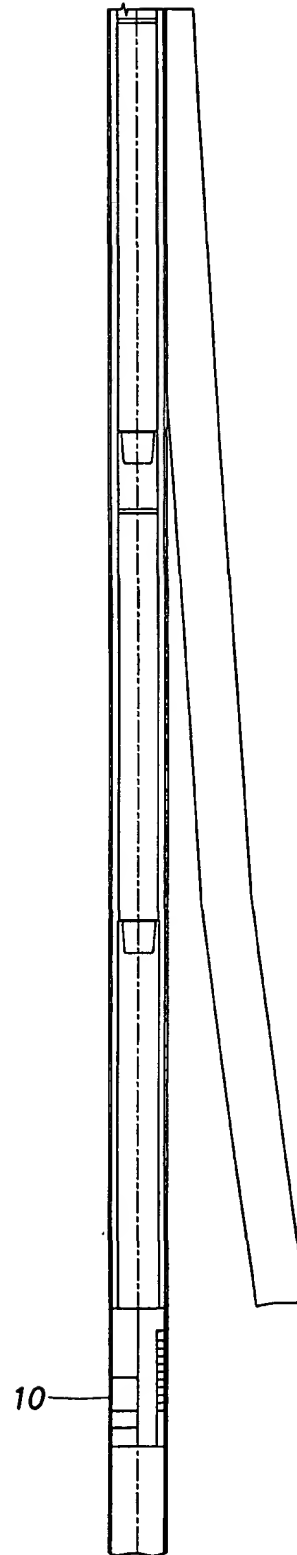


FIG. 25B3

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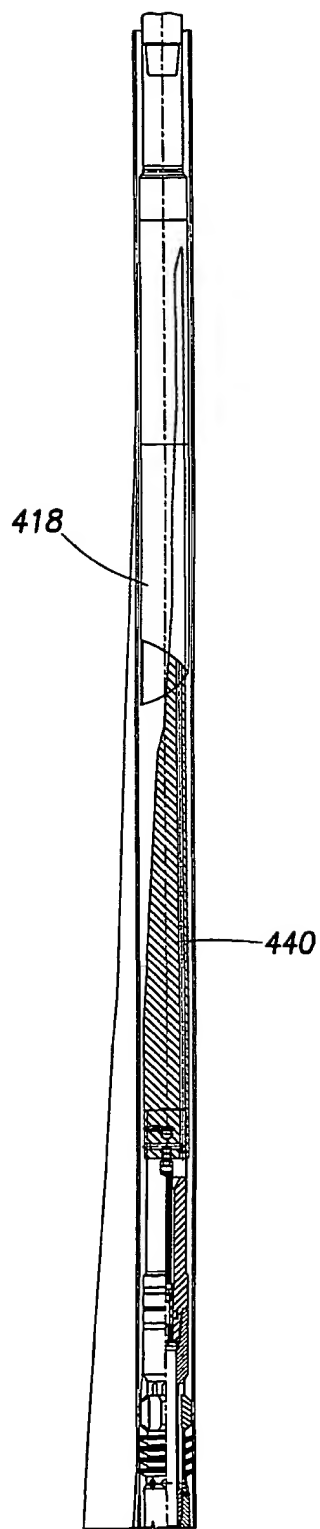


FIG. 25C1

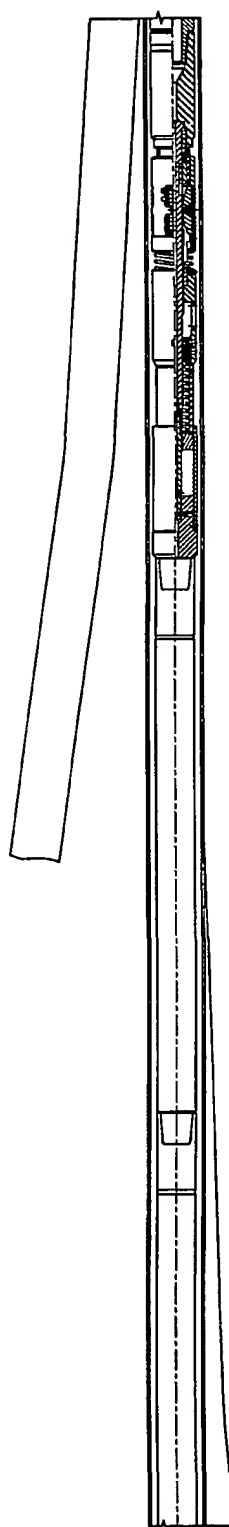


FIG. 25C2

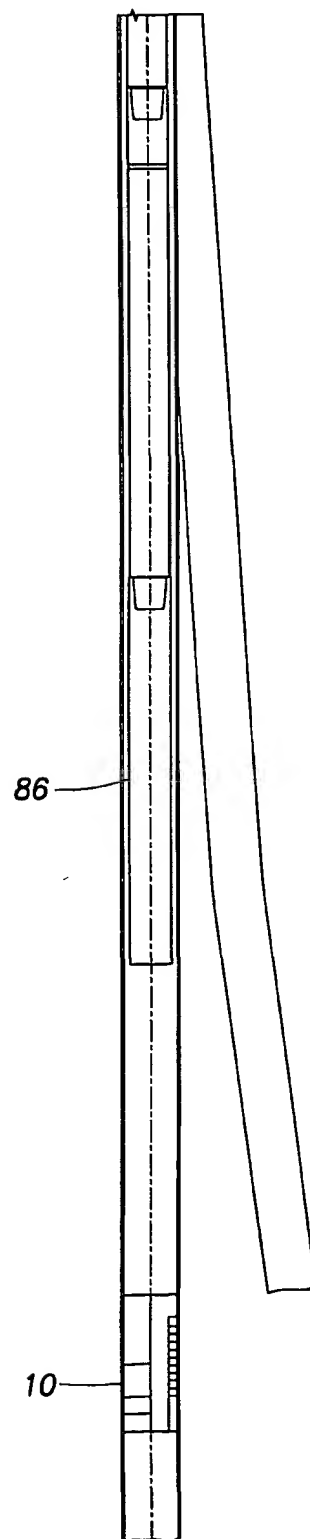


FIG. 25C3

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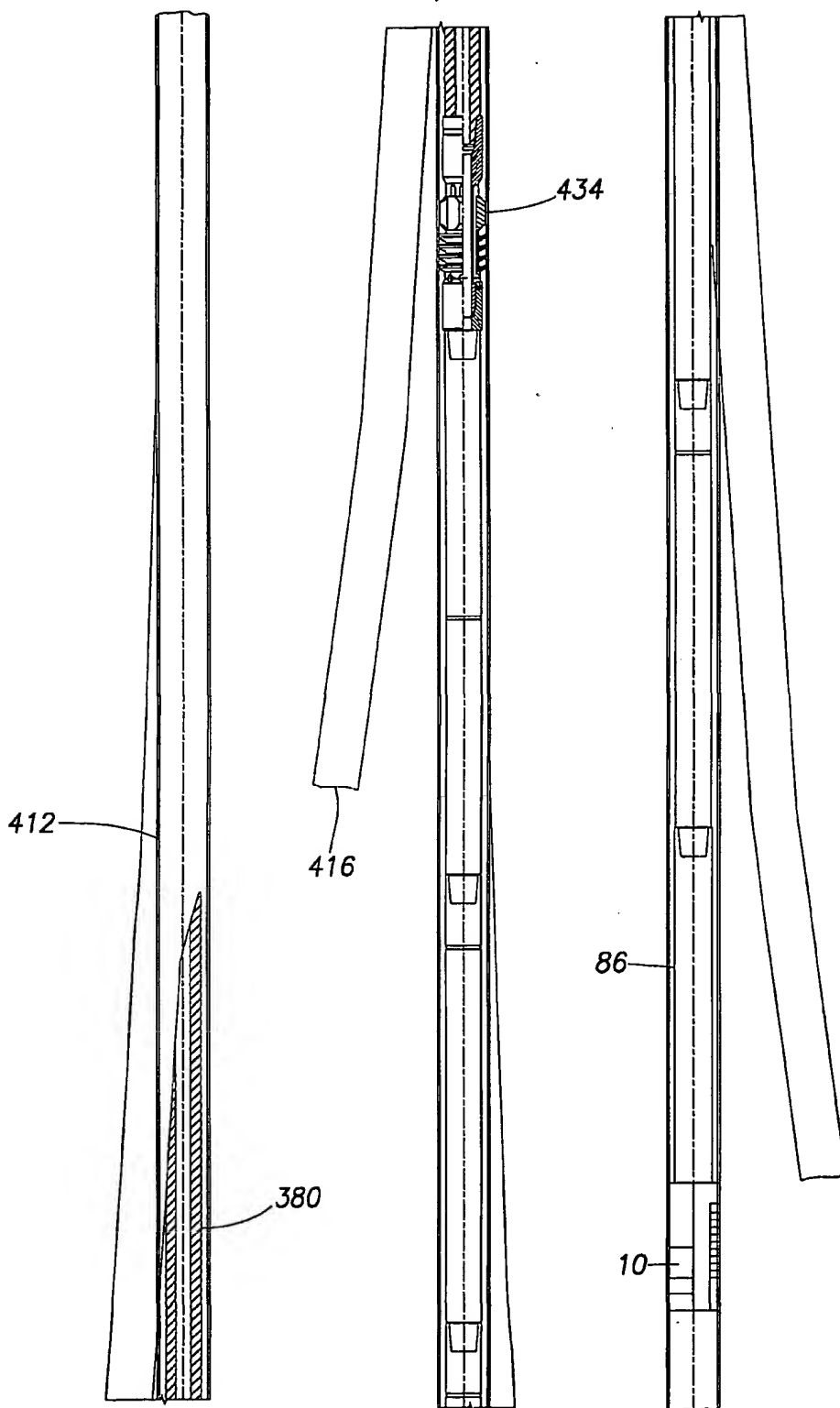


FIG.25D1

FIG.25D2

FIG.25D3

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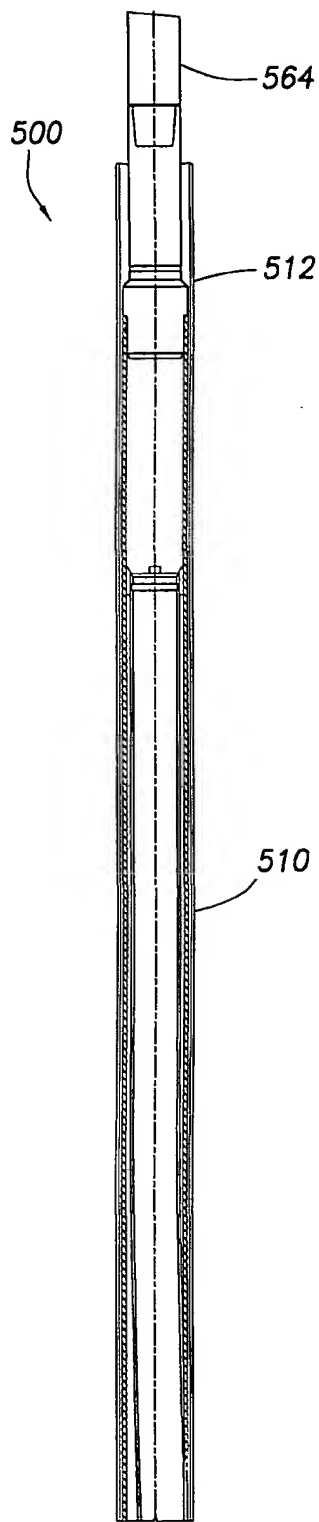


FIG. 26A1

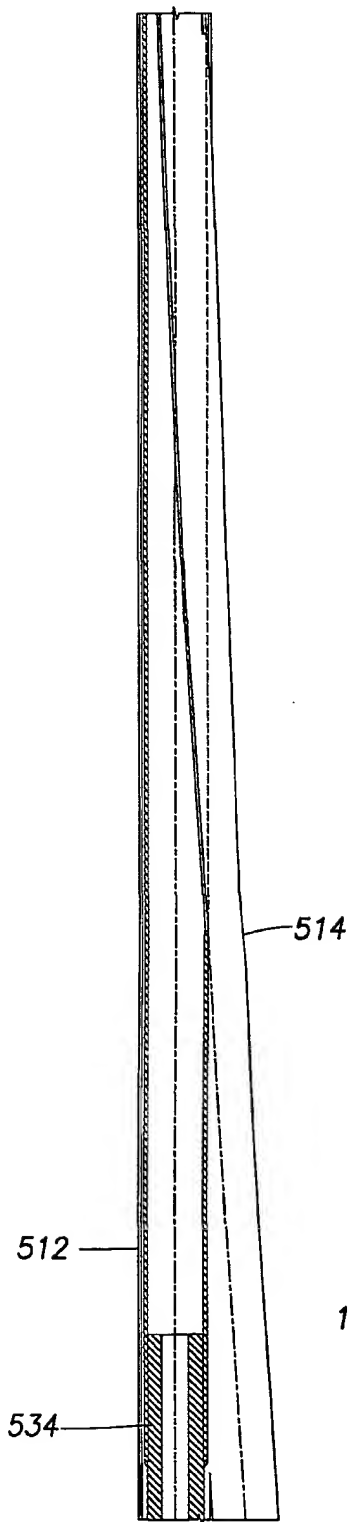


FIG. 26A2

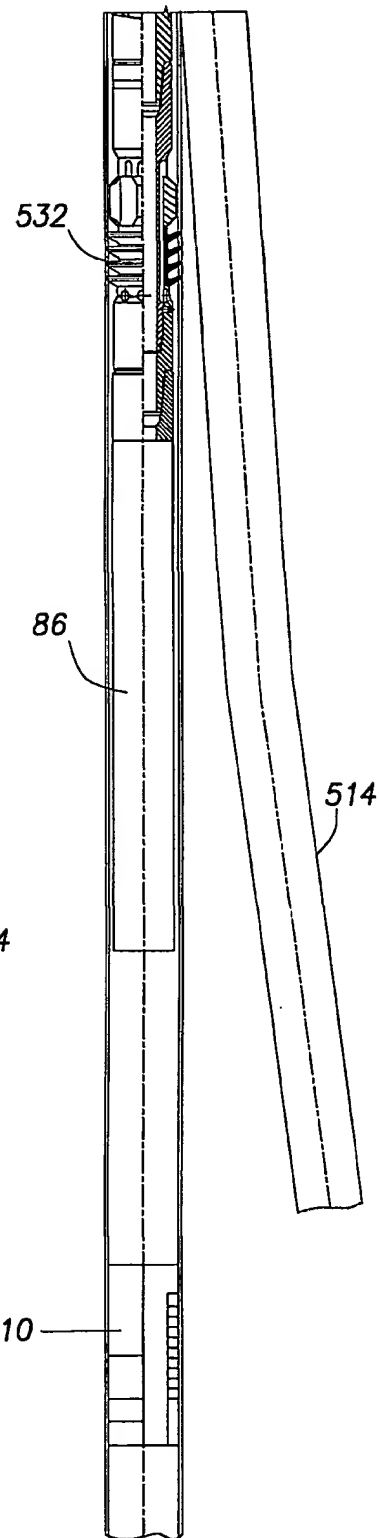


FIG. 26A3

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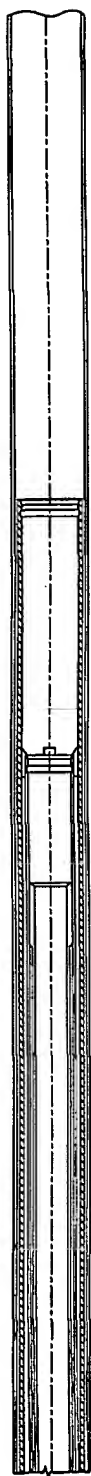


FIG. 26B1

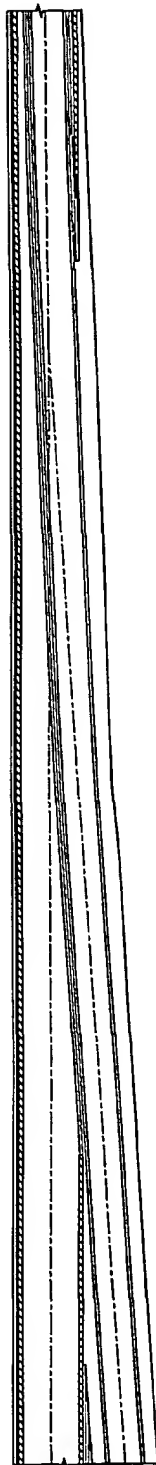


FIG. 26B2

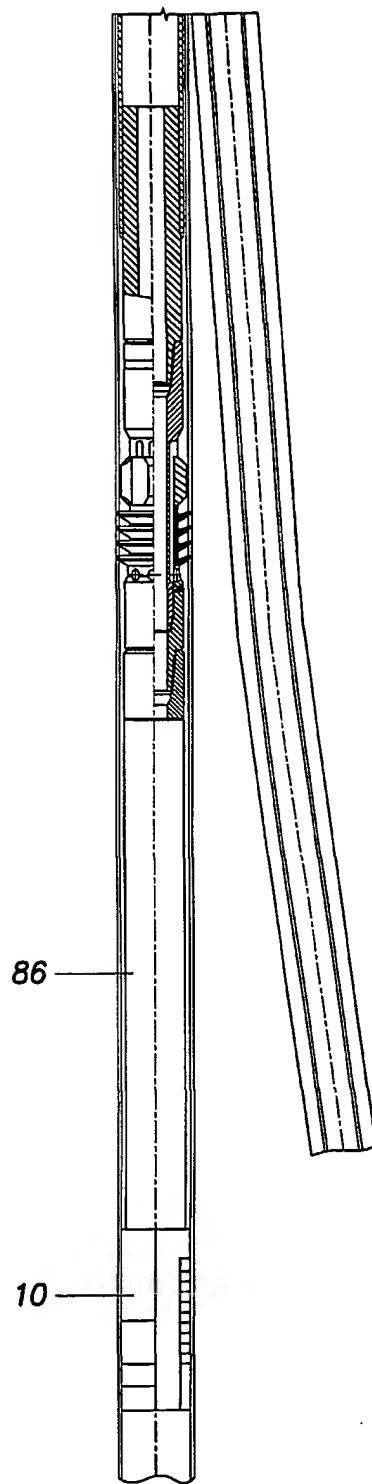


FIG. 26B3

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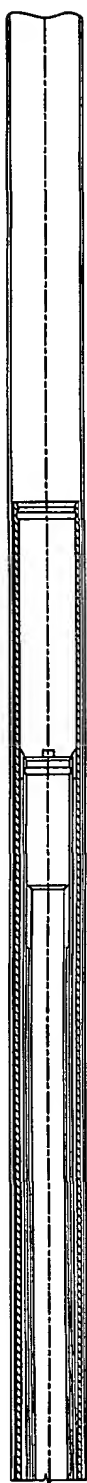


FIG. 26C1

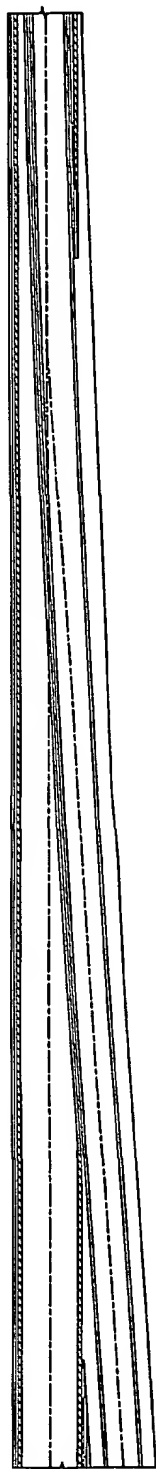


FIG. 26C2

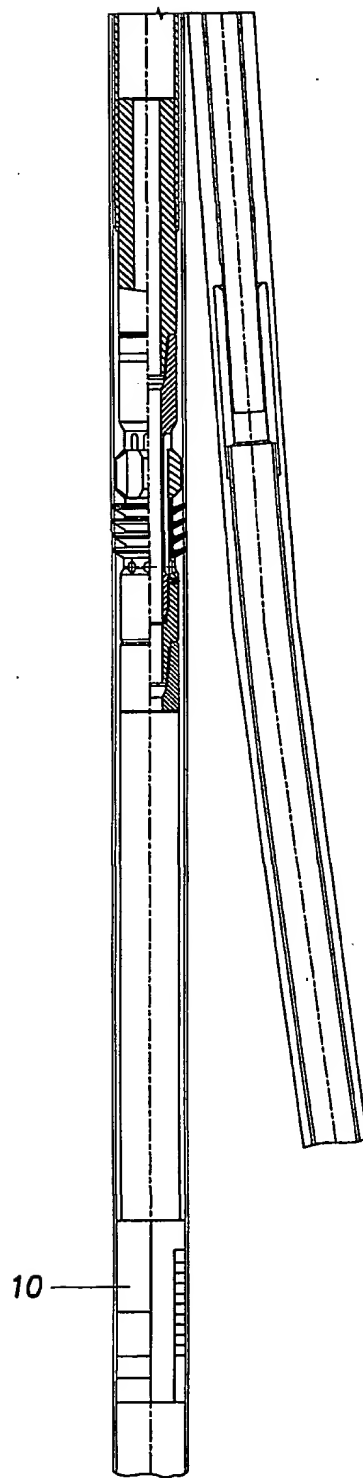


FIG. 26C3

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/16442

## CLASSIFICATION OF SUBJECT MATTER

H E21B 47/09

US CL : 166/255.1, 387, 382, 50, 88.2, 117.6, 217; 175/61

According to International Patent Classification (IPC) or to both national classification and IPC

## FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/255.1, 387, 382, 50, 88.2, 117.6, 217; 175/61

Documentation searched other than minimum documentation to the extent that such documents are included in the fields

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

## DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 4,750,563 A (BAUGH) 14 JUNE 1988, see entire document.	1,2
	US 5,174,397 A (CURRINGTON) 29 DECEMBER 1992, see entire document.	1,2,5,6,8-11,13-16
	US 4,393,929 A (AKKERMAN) 19 JULY 1983, see entire document.	1
	US 4,440,223 A (AKKERMAN) 03 APRIL 1984, see entire document.	1
	US 4,732,212 A (FRASER) 22 MARCH 1988, see entire document.	1
	US 4,762,177 A (SMITH) 09 AUGUST 1988, see entire document.	1

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

Special categories of cited documents:	"I"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"A"	document member of the same patent family
document referring to an oral disclosure, use, exhibition or other means		
document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

05 AUGUST 2001

Date of mailing of the international search report

28 AUG 2001

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks

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Washington, D.C. 20231

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Authorized officer

ROGER SCHOEPPEL

Telephone No. (703) 308-2147

Form PCT/ISA/210 (second sheet) (July 1998)\*

SUBSTITUTE SHEET (RULE 26)

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/16442

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,021,714 A (GROVE et al.) 08 FEBRUARY 2000.	



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/16442

**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-16

Remark on Protest

☐

The additional search fees were accompanied by the applicant's protest.

☐

No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US01/16442

## BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

- I, claims 1-16, an apparatus serving as a reference within a casing;
- II, claims 17-23, an apparatus to locate a well tool in a cased borehole;
- III, claims 24 & 25, a method of installing a reference member in a cased borehole;
- IV, claim 26, a method for setting a marker in a borehole; and
- V, claims 27-29, a method for milling a window.

The inventions listed as Groups I-V do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: They are related as subcombinations disclosed as separately usable in a single combination, as combination and subcombinations or as apparatus and process for using that apparatus.